THE
CHEMICAL RESISTANCE
OF
ENGINEERING MATERIALS

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The CHEMICAL CATALOG COMPANY, *Inc.*
19 EAST 24TH STREET, NEW YORK, U. S. A.
1923

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Press of
J. J. Little & Ives Company
New York, U. S. A.

OF IN
28 JAN 192

TO

K. GEORGE FALK

in grateful acknowledgment of his constant help and advice since my student days, my part in this book is dedicated.

M. L. H.

TO

W. LASH MILLER

to whom I owe most of what little chemistry I know, my part in this book is dedicated.

F. M. T., Jr.

Preface.

The occasion for this book was the situation that faced the chemical industries of this country in 1915-1918. At a time when, under the stress of war conditions, engineers with no previous chemical experience were called upon to build chemical plants, they were greatly handicapped by the lack of much necessary information in a readily accessible form. No collection was available of the known data on the action of industrial chemicals on construction and other engineering materials as far as the authors have been able to discover, and not even a moderately comprehensive bibliography existed to serve as a guide to the great mass of disconnected and widely scattered information in the literature on the chemical behavior of materials used in the construction of plants and apparatus.

In entering this neglected but important field the object of this book is threefold; it aims (a) to present the results of experiment and of general knowledge in a full but not necessarily exhaustive way, and wherever possible to give quantitative data; (b) to serve as a bibliography of the subject by referring to all the sources used; (c) to stimulate further research and publication along this line by showing what parts of the field are incompletely covered, and by suggesting ways of making results more generally comparable and hence more practically useful.

The authors, realizing the difficulties of covering a field of knowledge as extended as this one, have endeavored to make this modest volume representative rather than exhaustive. If, in addition to presenting useful knowledge in a condensed form, it shall have directed the attention of those interested to the necessity of further systematization of research along these lines and the no less urgent necessity of stating results in an intelligible way, it will have accomplished much.

Most manufacturing organizations possess more or less comprehensive information on the behavior of the engineering materials they handle. These organizations would perform a service to the industry at large as well as to themselves by publishing such data. If this book proves of sufficient use to warrant in time a revised edition, it is hoped to include a large amount of such fresh material.

The authors wish to express their gratitude to numerous manufacturers of equipment and of chemical products, and to various chemical engineers, who have contributed valuable suggestions and data for this book.

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THE CHEMICAL RESISTANCE OF ENGINEERING MATERIALS

I. Introduction.

The behavior of engineering materials towards chemicals with which they must come in contact is of importance to all those having a part in designing, building or operating a chemical plant, but to the designer it is of especial importance, since when materials are once erected and installed, modifications are enormously inconvenient and expensive. While the choice of materials usually presents itself to the architect and engineer in terms of materials available, mostly of well known characteristics, chosen on a basis of cost and strength, the designer of chemical plants and equipment attacks the problem from a slightly different angle. For him the controlling proximate factor is usually the chemical to be handled, and strength and apparent cost take second place; lead may not be too weak nor platinum too dear for him to use on occasion.

For this reason the data in this book have been arranged primarily according to the chemical materials handled, and secondarily according to the construction or engineering materials. This grouping, however, has not been adhered to strictly where it would involve the sacrifice of convenience and readability. Any inconsistency that may result from this plan is corrected by the index, the free use of which will make available all the data on a given material or chemical.

It is difficult to make sweeping generalizations where so many kinds of reactions are involved, but at least one broad classification of behavior may be made. There is an obvious difference, for example, between the slow action of an acid solution on the walls of a steel kettle, and that of an alkaline liquor on a wooden tank. In the first instance (since over any considerable area a metal can be assumed to be homogeneous) the deterioration of the steel is nearly proportional to the loss of weight per unit surface, and the action is comparatively uniform; only the surface is attacked, and the destroyed portion is largely dissolved or corroded away. In the second instance the deterioration bears no simple relation to the change in weight. Obviously the results of experiments on the deterioration of iron and wood must be expressed in different terms.

Engineering materials, then, may be divided into two main classes for the purpose at hand:—(a) comparatively homogeneous and non-porous materials, such as metals and alloys, that deteriorate chiefly on the surface alone, and (b) non-homogeneous, porous materials, usually of organic origin, like wood and textiles which deteriorate throughout the mass. The destructive action of chemicals on the first class (and most of the actions to be considered are destructive) can usually be best expressed as loss in weight per unit area per unit time; for the second class no rule can be laid down, but each case must be judged on its individual merits, changes in tensile strength, crushing strength, hardness, appearance of surface, etc., being indicated as appropriate indices of the resistance of the different materials.

Users of chemical engineering materials on a large scale are often prone to belittle any and all laboratory experiments intended to test the suitability of different materials. But laboratory experiments are justifiable and useful provided that everyone is fully aware that the results given are those of a laboratory experiment, and provided that the conditions of the experiment are accurately defined. Naturally, the more nearly the laboratory experiment can be made to duplicate the conditions met with in actual practice, the more it may be relied on.

In all experimental work of this kind it cannot be too strongly emphasized that the conditions of the experiment must be precisely defined, if the results are to be reproducible and comparable with other work—in other words, if they are to be of any real use. It is unfortunate that many independent investigators and many manufacturers of materials recommended as specially chemically resistant neglect this in publishing data. For example, results of the action of an acid on a metal, expressed in units of percentage loss of weight in a given time, are quite useless for comparison with the results of other workers, and there is no assurance that the results are comparable among themselves; the necessary datum of surface exposed is lacking. Fortunately results expressed in this way are found chiefly in older work.

In describing the conditions under which experiments are carried out, as many as possible of these conditions should be expressed quantitatively. Among the most significant are:—

Analysis of sample tested.
Composition of the destructive reagent (percentage of acid, alkali, salt, gas, etc.).
Temperature.
Rate or kind of agitation of solution, or lack of it.
Duration of experiment (possible variation of composition of solution and rate of action).

Acidity or alkalinity of destructive reagent (behavior towards indicators, or hydrogen ion concentration).
Presence of catalytic substances in solution.
Presence of non-electrolytes, sugar, gelatine, infusions from wooden containers, etc.
Contact with other metals (possible electrolytic effect).

There are, of course, many other factors of importance, such as condition of surface, presence of occluded gases, dissolved air in reagent, etc., which vary with each case.

Many factors that affect the results do not lend themselves to convenient quantitative expression, but may be indicated qualitatively; such as,

Color and surface changes.
Condition of surface of sample.
Appearance of coatings, precipitates or turbidity.

Even here, however, quantitative methods are attempted. Depth of pitting is estimated by buffing down the surface until the pits disappear and noting the thickness ground off.

The tremendous influence of agitation on the deteriorating action of chemical liquors is often underestimated. This was forcibly brought to the attention of one of the authors by the following circumstance:—Three identical steel tanks (former tank car bodies set on end) were used for a metallurgical leaching solution slight acid with sulfuric acid. The solution was agitated with compressed air in the second tank of the series; there was no agitation in the first tank; in the third tank the solution was slightly agitated owing to the turbulence caused by the pump. The center tank corroded very quickly so that it could no longer be used; the third tank outlasted the center one, but showed appreciable corrosion; the first tank was hardly corroded at all at the end of six months. Needless to say, iron tanks should not have been used for such a purpose at all, and were replaced with wooden tanks painted with an asphaltum paint.

Robert J. McKay * investigated the influence of agitation on corrosion in connection with the pickling of steel; he says:—"The rate of agitation must be controlled. Rates of corrosion of metals by acids are in general slower when there is no agitation, but they may be greater and may vary considerably in ratio from the rates under agitated conditions. Tests made under quiet conditions must be subject to large error on account of changes in the concentration of the corroding solution around the corroded surface, and because of the impossibility of preventing any movement of the solution, and of controlling the slight movements which must exist. For this reason practical

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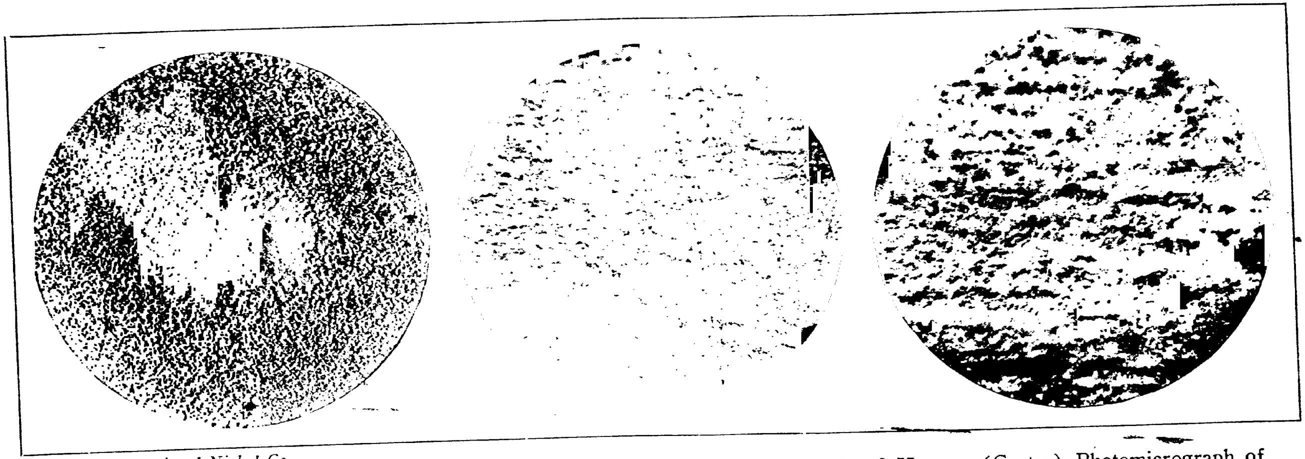
* Iron Trade Review, 1922, p. 963.



Courtesy International Nickel Co.

FIG. 1.—(Left) Air Jet Corrosion Through a ¼-inch Acid Resisting Alloy Plate in 48 Hours. (Center) Photomicrograph of Surface of Tie-rod Showing Effect of Electrolytic Corrosion. x 80. (Right) Photomicrograph of Surface of Tie-rod Showing Corrosion by Air and Acid. x 80.

conditions which closely approach quiet contact are the hardest to duplicate in the laboratory, but fortunately this is a condition which exists comparatively seldom in pickling work [or in any practical handling of corrosive liquors in metal chemical equipment: *authors*].

"In general, a gentle rate of agitation will increase the rate of quiet corrosion by 100 per cent or more and this corrosion will then be comparatively constant until the rate becomes violent. It has been shown that violent agitation, such as the action of a jet of air at about 15 pounds per square inch pressure in the corroding solution will produce greatly accelerated corrosion.

"The aeration of a pickling bath will increase the rate of corrosion of most anti-acid metals several times, and must therefore be one of the conditions most carefully studied. In tests to duplicate practice, the air contacts of the test must be arranged so as to produce the same average air concentration in the solution as exists in practice. The small total amount of oxygen soluble in solution must always be taken into consideration both in laboratory tests and in practice. The importance of this consideration has been shown by tests wherein the rate of a sample of metal agitated within one inch of the surface of a solution, the surface being in contact with air and no saturating apparatus being used, was twice that of a sample of the same metal handled in the same way, but immersed several inches deep.

"The possibility of changes in the concentration of the solution, and the possible effect of corrosion products both precipitated and dissolved, must be studied. Changes in concentration during corrosion may have a direct effect on the corrosion rate, but more important than this is the possibility of setting up corroding electrolytic cells by variations in concentration of the materials in solution from one point to another.

"It should be remembered in all attempts to apply laboratory results to practical corrosion problems that each form of corrosion is a problem of its own, and that the mechanism of the chemical action entering into the corrosion must be known to apply such results intelligently. For instance, the mechanism of the corrosion of the tie-rods in pickling tanks is entirely different from that of the corrosion of pickling pins, and requires a different form of apparatus for the study. Such differences must be even greater in pieces of apparatus used for more widely divergent purposes."

Mr. McKay's suggestion regarding concentration cells is very interesting as being the probable explanation of those apparently contradictory instances where agitation decreases corrosion instead of increasing it. There are also cases recorded where gentle agitation decreases the corrosion, but when the agitation is increased the corrosion is augmented. The explanation is probably that up to a certain point the beneficial effect of breaking up the concentration cells and homogenizing the liquid is greater than the detrimental effect of aeration and agitation. When the agitation becomes violent, the usual corrosion promoting conditions become preponderant.

Agitation with air is particularly interesting as three distinct influences seem to be involved (1) agitation (2) the chemical action of the air (3) erosion. Agitation with air brings new portions of the corroding liquid in contact with the corroded surface, just as in the cases of agitation with paddles or circulating pumps. It also tends to remove protective films in the same way. But in addition to the above it exerts a distinct chemical action in many instances.

This is in line with numerous cases in chemical engineering where a given material can be used for handling a corrosive liquid provided that air is excluded. Copper condensers are used with acetic acid stills, and are little affected if air is kept out. If the plant is shut down, the condensers and connections have to be thoroughly washed out with water to prevent their destruction. The same is true in the distillation of fatty acids through copper condensers. The chemistry of this phenomenon has never been thoroughly worked out, but possibly involves the greater ease of formation of the basic salts of these acids with copper.

The influence of other metals in contact with the metal being studied is of great importance as such contacts in the presence of a corroding solution are frequently met with in industrial work. Cast iron baffle plates in the blow-pits of sulphite pulp mills stand up better when iron bolts rather than bronze bolts are used, as has been the custom for years. The theory of such phenomena simply involves the usual problem of setting up electrolytic cells. However, in its practical application it becomes very complicated. Not only are there cases of one metal in contact with another, but of cells set up between different portions of the same mass of metal. Very small differences in composition, in structure or (apparently) in condition of the surface, may set up such electrolytic corrosion. Even differences in the strains set up in different portions of a mass of metal by the mechanical use to which it is subjected can be a cause of such action. Idle rails on a railroad corrode much more than busy rails.* This has been explained † on a number of grounds: (1) constant vibration causes shedding of rust; (2) vibration break up areas of different potential; (3) rise in temperature due to use vaporizes film of moisture; (4) films of oil; (5) electrolytic action set up between bright iron of top and dull iron of bottom of rail. The real explanation seems to be (5), although it is probably strains set up in the structure of the steel rather than the brightness, which is merely an attendant circumstance.

The impeller of a bronze exhauster remained bright after the casing, made of the same material, was heavily corroded. This was probably due to the constant shedding of corroded particles. In many instances corrosion seems to proceed according to some exponential law, and never gets very far if nuclei are not allowed to reach any considerable size after formation. It is a matter of common knowledge that nothing deteriorates so quickly around a chemical plant as idle equipment, and that even an occasional "dusting off" and "wiping up" of a piece of equipment will do much to keep it from becoming corroded.

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* Stephenson, Report British Assn. Advancement of Science, 1843, p. 78.

† Watts, Trans. Am. Electrochem. Soc., 33 (1918), 173.

The most important instances of corrosion being furthered by the contact of dissimilar metallic material, however, occur in connection with coated metals, many of which are in common use in general construction, and an even greater variety in chemical construction. Of such materials in common use we might mention tin plate, galvanized iron and terne metal. In the chemical industries we have lead lined iron, tinned iron and homogeneous lead, tin and silver lined copper.

Such coated metals present peculiar problems, and vary in their degree of liability to corrosion, depending on the electrochemical relations of the two or more metals, the porosity of the coating and the mechanical perfection of the bonding between the coating and the metal coated. This subject will be considered in a later chapter under rusting and atmospheric corrosion.

It is almost impossible to classify corrosion reactions from any theoretical point of view, or according to any orderly scheme based on natural law. Some corrosive reactions are simple cases of solution, others are replacement reactions, still others involve oxidation and reduction. Many different types of reaction are considered in the following chapters. The type most commonly met with in the corrosion problems of chemical plants is that in which an ionizable hydrogen or metal (in an acid or a salt) is replaced by a more positive metal. The solution of iron by dilute sulfuric acid:—

$$Fe + H_2SO_4 \longrightarrow FeSO_4 + H_2$$

in which hydrogen is set free, is a common example. To the same class belongs the less frequently encountered reaction between metallic iron and the copper salts:—

$$Fe + CuSO_4 \longrightarrow FeSO_4 + Cu$$

in which copper is set free, which reaction is utilized in the precipitation of copper from mine water on scrap iron. All dilute acids, and many metals react in this way.

The concentration of the acid is frequently the determining factor in the reaction. For instance the equation:—

$$Cu + 2H_2SO_4 \longrightarrow CuSO_4 + 2H_2O + SO_2$$

represents what takes place between copper and *strong* sulfuric acid, but when the sulfuric acid is dilute the reaction (with zinc) is:—

$$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2$$

Nitric acid acts differently from sulfuric, hydrochloric and most other acids, on account of the fact that it enters into reactions as an oxidizing agent, as well as an ordinary acid group. For instance, nitric acid with tin gives metastannic acid H_2SnO_3. For this reason, nitric acid often appears not to act on a metallic surface at all. It coats the metal with a layer of insoluble oxide, hydroxide or other compound, and then ceases to act. This reaction forms a basis for one explanation of the passivity phenomena which will be referred to at length in a subsequent chapter.

To return to the consideration of the simple reactions in which an ionizable hydrogen or metal is replaced by a more electropositive metal, it should be noted that such reactions depend on the ionization of the acid or salt in solution. Since concentrated acids are not at all, or only very slightly, ionized, their reactions with metals are of the other types described, usually involving the destructive reduction of the acid, and the oxidation of the metal. In most cases such reactions require a high temperature to acquire any considerable velocity. The action of concentrated sulfuric acid on iron, copper and mercury is of this type (see following chapters).

Further attempts to classify corrosion reactions would hardly seem to be demanded in a work such as this, since they vary greatly and are exceedingly complex, especially those in which organic materials are involved; the reactions (described in a later chapter) of organic halides with metals will serve as a reminder that many classes of compounds, other than acids, caustic alkalis and their salts may be corrosive.

As an example of the complexity of organic corrosive reactions might be mentioned the case of tetrachlorethane, now widely used as a solvent, which actively attacks metals, both when free from water (in contradiction of some published statements), as well as in its presence. A tentative view has been put forward by Sastry* that under the influence of heat, and in the presence of metals, tetrachlorethane loses a molecule of hydrogen chloride, giving trichlor-ethylene, as follows:—

$$CHCl_2.CHCl_2 \longrightarrow HCl + CCl_2:CHCl.$$

The hydrochloric acid then acts on the metals. This seems improbable, however, since dry hydrogen chloride is not corrosive. The reaction, where it occurs dry, is probably similar to a Würtz reaction.

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* J. Soc. Chem. Ind., 35 (1916), 94.

Complex as these cases of corrosion are, they are of considerable importance owing to the extensive use of chlorinated organic compounds as solvents in various commercial processes of solvent extraction of oils and fats, and their effect on various metals will be discussed in detail in a later chapter.

In the following pages an attempt has been made to summarize the reliable and useful data available both from laboratory experiments on the deterioration of materials in contact with corrosive liquids and from the observations of practical plant operating men. As with most technical subjects, what is known today is little in comparison with what remains to be found out. It is to be hoped that there will be more co-operation in the future between plant engineers, builders of equipment and manufacturers of metals and other materials.

Builders of equipment are often expected to accomplish miracles by supplying successfully resistant pumps or valves when the data given them are incomplete or actually misleading. As an illustration of this, an equipment manufacturer was asked to supply a hard rubber pump for handling a solution containing dilute hydrochloric acid, the concentration of which was definitely expressed. A few weeks after the pump was put in operation the manufacturer was informed that it had softened, swollen, disintegrated in part, and was useless for further service. On investigation it was found that the liquor being pumped contained about 40 per cent mixed hydrocarbons! It was really an emulsion. The plant manager had allowed the emulsion to separate, estimated the acid content of the water layer, and communicated that to the equipment manufacturer, secure in the belief that as far as destructive influence was concerned, only the acid mattered.

It should be realized that the modern manufacturer of chemical plant equipment is usually to be considered as an engineer, rather than a merchant, and as a rule he can be depended on for much expert advice in the selection of materials. It will usually be found profitable to take up unusual problems with the reliable builders of the type of equipment under consideration, placing all necessary data before them for consideration. Much of the progress in the last few years in the proper selection of materials, and in the introduction of new materials, has been due to the enterprise of equipment builders, and much of our progress in the future must depend on a true spirit of co-operation between the manufacturers of materials, the manufacturers of equipment and the operating executives who use the equipment in plant and laboratory.

II. Sulfuric Acid and Metals.

I. Sulfuric Acid and Iron.

Sulfuric acid is the most widely used manufactured chemical in both chemical and non-chemical industries. Not only its manufacture but its handling and storage have been exhaustively studied, and the results of this study furnish a large number of data concerning its action on engineering materials. Because of the importance of iron in civilization and industry [1] and because iron satisfactorily resists the attack of certain strengths of sulfuric acid, information as to the behavior of iron and iron alloys is abundant.

Technically and industrially sulfuric acid plays a double rôle in its chemical behavior, for unlike nitric and hydrochloric acid it is easily manufactured practically water-free and is stable in this condition. Acids may be divided for convenience into two classes according to their destructive action on metals: (a) Non-oxidizing acids, such as hydrochloric, that attack metals by virtue of being acids, i. e. forming salts with bases and producing hydrogen ions when dissolved in water; and (b) oxidizing acids that attack metals by oxidation as well as by the formation of salts or the production of hydrogen ions.* In the behavior of concentrated sulfuric acid, particularly at high temperatures, oxidation reactions play a prominent part; concentrated sulfuric acid is little ionized, and its salt forming ability, especially with less active metals like iron, is less marked. Dilute sulfuric acid, on the other hand, acts towards metals in most cases simply as an acid, and causes little or no oxidation. Since in an oxidation the oxidizing agent is itself always reduced, these facts may be summed up in another way: concentrated sulfuric acid, particularly at high temperatures, is easily reduced by many metals; dilute sulfuric acid is not.

Sulfuric acid has another peculiarity in that it may be made of apparently greater than 100 per cent strength; in other words its water content may be in effect reduced to less than nothing. This seeming paradox is due to the fact that acids of an apparent strength greater than 100 per cent are actually mixtures of sulfuric acid, H_2SO_4, and its anhydride, SO_3. The latter may be considered potential sulfuric acid, requiring only union with water to make it actual sulfuric acid; hence mixtures of sulfuric anhydride with the acid have many characteristics of a more concentrated acid than the 100 per cent product.

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* See p. 46 below, the electromotive series of metals.

While sulfuric anhydride, SO_3, sulfuric acid, H_2SO_4, and its hydrates, $H_2SO_4.nH_2O$, are definite chemical individuals, the chemical properties of their mixtures vary smoothly, though passing through maxima and minima, from the most dilute acid to simple SO_3.

Sulfuric acid of more than 98 per cent H_2SO_4 content is known as oleum or fuming sulfuric acid, since it gives off fumes of free SO_3 when heated.

All strengths of pure sulfuric acid up to 100 per cent are colorless liquids at ordinary temperatures; certain strengths of oleum are solid, as is pure sulfuric anhydride. Ordinary concentrated acid is an oily liquid with a specific gravity of 1.84. Technical sulfuric acid is dark gray or brown to colorless according to its purity, and usually deposits a sediment on standing.

The commoner strengths sold are:

Per Cent H_2SO_4	Degrees Baumé	Specific Gravity	Boiling Point
104	....	....	....
93	66°	1.835	281° C.
78	60	1.706	197
62	50	1.526	146

The facts concerning the behavior of different grades of iron and steel towards sulfuric acid are fairly well known, but the reasons for the variations are not definitely agreed on. While the behavior of a pure metal on first contact with an acid of given concentration may be predicted with considerable certainty, the presence of foreign substances has a disturbing effect which is often great enough to mask entirely the fundamental reaction. Since commercial metals, notably iron, are never pure, predictions as to their behavior not based on actual experiment must be made and accepted with caution.

Alloys and metals containing foreign substances, or in other words all commercial metals, may be homogeneous, or they may be mixtures of several solid phases of varying composition, chemical properties and electrical characteristics. Their behavior towards acids will depend chiefly on: (a) the chemical characteristics of the individual phases taken alone,. as for example their solubility in sulfuric acid; (b) the electrochemical relationship between the phases which may result in accelerated action due to differences in potential between phases; (c) the formation of protective coatings, as for example of gas or insoluble salts, which retard or stop the action. These factors already touched on in the first chapter will not be discussed here from a general theoretical point of view, but will be referred to from time to time.

Cast iron, wrought iron and steel vary in their chemical as well as in their physical characteristics. This is illustrated by their behavior towards sulfuric acid. In general concentrated sulfuric acid acts but little on any of these in the absence of moisture; the action increases as the temperature rises; dilute acid acts less on cast than on wrought iron; the action of sulfuric acid on iron alloys varies greatly, but alloys containing considerable silicon and many containing chromium are extremely resistant.

Ordinary Cast Iron.

As has been said, concentrated sulfuric acid acts only slightly on cast iron, and in the absence of air at ordinary temperatures this is true of acids as dilute as 62 per cent. At 100° C., however, while the action of 93 per cent acid is still slight that of 78 per cent acid is 1½ times, and of 62 per cent acid 3 times as great as the action of 93 per cent acid.

Comparison of the action of the acids at their boiling points shows a still greater variation with concentration. The action of 93 per cent acid at 281°, even when it contains a little N_2O_3 or SO_3, is still almost negligible, but at 197° that of 78 per cent acid is 20 times as great, and is 14 times as great as the action of 78 per cent acid at 100°. Ninety three per cent acid at 281° acts less vigorously on cast iron than 78 per cent acid at 100°. Acid of 62 per cent strength acts less on cast iron at 146° C. than 78 per cent acid at 197° C., but fourteen times as much as 93 per cent acid at 281° C. In this case there is no difference between pure and commercial acid.

A table may be made showing these relationships at a glance. The action of 93 per cent acid at 281° C. is taken as 1, and the actions under the other conditions shown on that basis:

Per Cent H_2SO_4	Temperature			
	281° C.	197° C.	146° C.	100° C.
93	1	....	....	1
78	....	20	....	1.4
62	....	....	14	....

Such an expression of results is of course not strictly quantitative, but is a convenient way of bringing out the general facts.

It is obviously not feasible to concentrate acid of 78 per cent strength in iron, but 93 per cent acid may be handled in this way.

The various kinds of cast iron do not differ in their behavior towards 93 per cent acid at any temperature, nor towards weaker acids below 100° C., but the more dilute acids at their boiling points act decidedly less on charcoal pig and on chilled cast iron than on any other kind, and to the greatest extent on Scotch pig or mixtures containing it. No difference has been found between hot and cold casting.[2]

Although cast iron is comparatively little dissolved by fuming sulfuric acid,[3] it is cracked by its action, sometimes with almost explosive violence. Failures of this kind occurring in cast iron chemical apparatus were formerly attributed to gases produced under heavy pressure in the interstices of the metal by reactions in which sulfuric acid is reduced to sulfur dioxide and hydrogen sulfide and in which carbon dioxide is formed. More recent work, however, indicates another cause. Free sulfur trioxide (SO_3), as it is present in oleum readily oxidizes silicon either free or alloyed with iron, and the greater volume of the silicon dioxide (SiO_2) produced in the pores of the casting produces a condition of internal strain that may eventually result in the cracking or bursting of the metal.[4] Cast iron should, in order to resist acids, have a high total and low graphitic carbon content, the reverse of the conditions necessary for alkali-resisting iron.[5]

Wrought Iron and Steel.

Of even greater practical importance than the action of sulfuric acid on cast iron is its action on steel. The following table shows the action of various strengths of acid on three different kinds of iron at ordinary temperatures.[3] The metals tested had the following carbon contents:

	Total Carbon	Graphitic Carbon
Cast Iron..............	3.55%	2.787%
Mild Steel..............	0.155	......
Wrought Iron...........	0.076	......

ACTION OF SULFURIC ACID ON IRON

Loss in Grams per Square Meter per Hour During 72 Hours at 18°-20°.

H_2SO_4 %	SO_3 %	Cast Iron	Mild Steel	Wrought Iron
48.8	39.9	0.2177	......	......
61.2	50.0	0.1510	......	0.3032
67.7	55.3	0.0847	......	0.0789
73.4	59.9	0.0662	......	0.0623
79.7	65.0	0.1500	......	0.1159
83.7	68.4	0.1388	.....	0.1052
85.1	69.5	0.1306	......	0.1034
88.2	72.0	0.1630	......	0.1417
90.6	73.9	0.1760	.....	0.1339
92.0	75.2	0.0983	......	0.1040
93.0	75.9	0.0736	......	0.0855
94.1	77.0	0.0723	0.0933	0.0708
95.4	77.9	0.1274	0.1471	0.1209
96.8	79.0	0.1013	0.0815	0.0988
98.4	80.3	0.0681	0.0533	0.0655
98.7	80.6	0.0583	0.0509	0.0570
99.2	81.0	0.0568	0.0418	0.0504
99.3	81.07	0.057	0.042	0.056
99.5	81.25	0.060	0.038	0.049
99.77	81.45	0.066	0.042	0.049
100.0	81.63	0.087	0.088	0.076

Total SO_3 %	Free SO_3 %			
81.8	0.91	0.201	0.393	0.323
82.02	2.00	0.190	0.285	0.514
82.28	3.64	0.132	0.441	0.687
82.54	4.73	0.154	0.956	1.075
82.80	7.45	0.151	0.566	1.321
83.50	10.17	0.079	0.758	1.540
84.20	12.89	0.270	1.024	0.892
84.62	16.16	0.271	1.400	0.758
85.05	18.34	0.076	1.988	1.530
86.00	23.78	0.070	0.245	0.471
88.24	34.67	0.043	0.033	0.053
90.07	45.56	0.040	0.018	0.019

At first glance the most striking feature of the table is the irregularity of the figures giving the weights dissolved compared with the strengths of the acid used. Some generalizations may, however, be made. The actions on cast iron and wrought iron are about the same with strengths up to 100 per cent, but oleum containing up to 24 per cent free SO_3 acts considerably less on cast iron. The action on steel is similar to that on wrought iron, but steel is slightly less acted on by acids of 98-100 per cent, and slightly more acted on by oleum of 13-18 per cent free SO_3.

It is interesting to apply these figures to a hypothetical case based on conditions actually found in practice. Sulfuric acid of 93 per cent strength (66° B.) would dissolve a steel tank at a rate of approximately 0.1 g. per sq. m. per hour. If the tank had a circumference of 6 m. (somewhat less than 2 m. in diameter), and a length of 4 m., its area would be 24 sq. m. It would therefore be dissolved at the rate of 58 g. per day, or 1.7 kg. per month. The specific gravity of iron being taken as 7, a layer 0.01 mm. thick would be dissolved in a month, provided the dissolution continued at the same rate during the whole time. Oleum with 18 per cent free SO_3 would act nearly twenty times as fast. That the question of the life of a tank cannot be settled definitely in quite such an offhand way is indicated by the fact that in such cases the rate of action is usually not constant, and generally decreases.

A table of figures given by Lunge,[2] is quite different from that just discussed. The experimental conditions were somewhat different, for the action was continued for six days instead of 72 hours, and no analysis is given of the metals tested, either or both of which facts may account for the difference, assuming that there has been no typographical error:

ACTION OF 100 PER CENT H_2SO_4 ON CAST AND WROUGHT IRON

	Loss, Per Cent		Loss, g/sq. cm.	
Metal	6 days at 20°	2 hours at 100°	6 days at 20°	2 hours at 100°
Cast Iron......	0.041	0.071	0.062	0.015
Wrought Iron..	0.175	0.313	0.056	0.095

The last two are of course the significant columns. If the second 20° column is calculated in terms of grams per square meter per hour, the relatively enormous figure of 4.3 is obtained. If, however, a typographical error was made in expressing the results, and they should have been in grams per square decimeter (as is the case with other tables), the figure would be 0.043, in fair accord with the values of the previous table.

Wrought iron is practically passive towards the stronger grades of oleum,[3] and a substantially iron free product may be made in apparatus constructed of it. The maximum attack is by oleum containing in the neighborhood of 20 per cent free SO_3, which is also the range of oleum of relatively high electrical conductivity.

A more recent study of the action of concentrated sulfuric acid on iron and steel has been made[6] under conditions making its results directly applicable to industrial practise.

Laboratory experiments were conducted on the action of strong sulfuric acid on the following samples of iron and steel. The gas produced by the reaction was collected, measured, and in some cases analyzed.

A. Steel plate: carbon 0.35 per cent, manganese 0.61, phosphorus 0.06, silicon 0.01, sulfur 0.01.

B. Steel cut from a sulfuric acid drum: carbon 0.045 per cent, manganese 0.375, phosphorus 0.004, sulfur 0.015, silicon 0.007, nickel 0.46.

C. Steel wire: carbon 0.51 per cent, manganese 0.48, phosphorus 0.046, silicon 0.083, sulfur 0.058.

D. Wrought iron.

E. British pig iron, No. 1 Foundry (soft, gray).

F. White cast iron (British).

G. Cast iron from Lithgow, N.S.W., cast in sand: carbon, graphite, 3.16 per cent; carbon combined, 0.57; silicon, 3.27; sulfur, 0.019; phosphorus, 0.792; manganese, 1.51.

H. Cast iron from Lithgow, N.S.W., cast in chill: carbon, graphite, 2.88 per cent; carbon, combined, 0.53; silicon, 3.46; sulfur, 0.024; phosphorus, 0.789; manganese, .52.

I. Iron powder obtained by reduction of ferric oxide with hydrogen.

The experiments were conducted mainly with sulfuric acid "Pure for analysis" which contained 97.5 per cent of sulfuric acid by analysis. Unless otherwise expressly stated, this is the acid used as "concentrated sulfuric acid."

With steel wire (C) and concentrated sulfuric acid the following results were obtained:

EFFECT OF TEMPERATURE ON COMPOSITION OF GAS

Temperature	Time from Start of Experiment Till Taking of Sample	H_2	SO_2
25° C.	8 days	96.8%	3.2%
30° C.	18 days	98.0	2.0
30° C.	54 days	95.1	4.9
35° C.	3 days	92.5	7.5
35° C.	6 days	92.0	8.0
35° C.	8 days	93.2	6.8
160° C.	½ hour	55.2	44.8
160° C.	2 hours	54.5	45.5
160° C.	4 hours	57.8	42.2
160° C.	7 hours	61.0	39.0
160° C.	16 hours	17.9	82.0
160° C.	30 hours	8.4	91.6
180° C.	1 hour	——	100.0
200° C.	1 hour	——	100.0

EFFECT OF TEMPERATURE ON VOLUME OF GAS

"Time" in the second column is the elapsed time at the indicated temperature only.

Iron Used	Time (Days)	Temperature	Rate in c.c. per Hour per Sq. Dm.	Temperature Coefficient for 10° C.
B.	35	30	0.08	—
B.	6	50	0.07	—
B.	1	100	0	—
B.	1	150	28	—
*C.	43	30	0.08	—
	8	35	0.26	9.5
	13	40	0.71	6.9
	1	55	2.6	2.5
	1	100	7.7	1.3
†C.	1	100	2.0	—
	0.2	150	59	2.0
	0.5	160	229	3.9
	0.1	180	1916	2.9
E.	20	30	0	—
	7	50	0	—
	1	100	2.4	—
	0.5	150	152	2.3
	0.5	165	270	1.5
F.	20	30	0.04	—
	1	50	1.0	3.3
	0.5	100	155	2.9
	0.5	150	5865	2.1
H.	30	30	———	—
	13	35	———	—
	6	40	———	—
	9	50	0.04	—
	1	100	1.40	2.0
	1	150	12.7	1.6
	1	165	128	4.0

* Same reacting substances heated first at 30° and temperature then raised.

† Fresh iron and acid used for high temperatures.

EFFECT OF COMPOSITION OF METAL

Lithgow Pig Iron (H)

Temperature	Time	H_2	SO_2
150° C.	4 hours	7.7	92.3
150° C.	6 "	3.9	96.1
165° C.	1 "	—	100.0
165° C.	3 "	—	100.0

British Pig Iron, No. 1 Foundry (E)

Temperature	Time	H_2	SO_2
100	5 hours	35.0	65.0
150	3 "	—	100.0
165	3 "	—	100.0

British White Cast Iron (F)

Temperature	Time	H_2	SO_2
30	12 days	35.0	65.0
50	24 hours	1.0	99.0
100	1 hour	—	100.0

Steel Plate (A)

Temperature	Time	H_2	SO_2
30	14 days	97.0	3.0
30	50 "	94.7	5.3

RATE OF REACTION

Sample, steel wire (C); area, 1.43 sq. cm.; surface, freshly polished with emery cloth; volume of concentrated sulfuric acid, 60 c.c.

Time in Days	Temperature °C.	C. c. Gas Evolved Per Hour Per Sq. Dm.
6	30	0.06
8	30	0.08
10	30	0.08
14	30	0.08
16	30	0.10
20	30	0.09
21	30	0.10
22	30	0.10
23	30	0.09
24	25	0.03
27	25	0.03
29	25	0.02
31	25	0.01
34	25	0.00
35	30	0.14
37	30	0.12
39	30	0.11
41	30	0.13
42	30	0.13
43	25	0.06
49	25	0.06
51	25	0.06
52	25	0.05
53	25	0.03
57	25	0.02
59	25	0.05
60	25	0.02
64	25	0.02
72	25	0.00

AVERAGE RATE OF GAS EVOLUTION DURING THE FIRST TWENTY DAYS AT 30° C.

Iron Used	Weight of Iron g.	Surface of Iron sq. cm.	Quantity of Acid c. c.	C. c. per Hour per Sq. Dm.
A.	37	60	120	0.05
B.	40	60	120	0.05
C.	20	143	60	0.08
D.	30	62	120	0.005
E.	37	67	120	0
F.	37	170	120	0.035
G.	37	68	130	0
H.	38	67	120	0

EFFECT OF ACID CONCENTRATION ON COMPOSITION OF GAS

Time, one week

Acid per cent	Temperature	Iron Used	H_2	SO_2
97.5	30° C.	Steel wire	96.5	3.5
94.6	30° C.	"	96.2	3.8
94.6 (commercial)	26° C.	B	98.8	1.2

EFFECT OF ACID CONCENTRATION ON VOLUME OF GAS

Sample, 20 g. steel (C); surface, 143 sq. cm.; temperature 30° C.

Acid Used per cent	Time from First Contact in Days	Rate in c. c. per Hour per Sq. Dcm.
97.5 by analysis	6	0.07
97.5 by analysis	12	0.08
96.0 by density	2	0.03
	3	0.16
	6	0.37
	10	0.37
94.6 by density	1	1.0
	8	1.5
	12	2.37

Another investigation of the effect on the corrosion of steel of rotating the steel surface in the corroding liquid [68] has resulted in the following conclusions:

The fundamental equation is undoubtedly

$$Fe + 2H^{+} \rightleftarrows Fe^{++} + 2H \qquad (1)$$

The rate at which hydrogen is removed is, in general, the most important factor determining the progress of corrosion. It is dependent on several important variables, and a study of this factor as affected by these variables offers the most logical method for investigating the process of corrosion in acids.

Hydrogen can be removed in two ways—by evolution of gaseous hydrogen, according to the reaction

$$2H \rightleftarrows H_2, \qquad (2)$$

or by depolarization by oxidation, either by dissolved oxygen

$$2H + {}^1/_2\,O_2 \rightleftarrows H_2O \qquad (3)$$

or by some other oxidizing agent.

Corrosion at rest is primarily determined by the rate of hydrogen gas evolution, particularly with the stronger acids.

The effect of velocity is to decrease the rate of the hydrogen gas evolution. Velocity decreases the size of hydrogen bubble or throws off the gas nuclei which aid bubble formation, and hence, by increasing the work to be done in forming hydrogen, increases the over-voltage.

Velocity increases corrosion by oxygen depolarization, since it thins down the effective film through which oxygen must diffuse. At high velocities the oxygen effect becomes so predominating that acids varying five hundred fold in concentration give the same corrosion.

The net corrosion observed, being the sum of two effects, is chiefly determined by gaseous hydrogen evolution at very low velocities and by oxygen depolarization at high velocities, and passes through a minimum point in the intermediate ranges.

Concentrated sulfuric acid (94.6-97.5 per cent) acts at the ordinary temperature on steel and some kinds of cast iron, the products being ferrous sulfate and hydrogen, with a small quantity of sulfur dioxide. As the temperature rises the reaction proceeds more rapidly but with a changing course, and at 180° the gaseous products are sulfur dioxide with occasional small quantities of hydrogen sulfide, but no hydrogen. The rate is increased on an average of about three times for each 10° rise.

The rate of reaction depends on the concentration of the acid, but for small dilutions the ratio of hydrogen to sulfur dioxide remains almost unchanged.

Although the rate of reaction depends to a certain extent on the composition of the samples of iron (as indicated by the large difference between steel wire and pig iron), an important factor governing the reaction with any one sample appears to be the condition of the surface.

Other generalizations warranted by the results are: 1. The action of 80-90 per cent sulfuric acid on steel is noticeably increased by shaking, probably by mechanical removal of ferrous sulfate from the surface; 2. 97.4 per cent and 89.3 per cent acids have less action on steel than 94 per cent, 90.9 per cent, 87.9 per cent or 85 per cent acids; 3. the $FeSO_4.H_2O$ formed on the surface slows down and sometimes inhibits the action altogether; 4. no real similarity exists between iron made passive by dipping in nitric acid of 1.4 s. g. and iron that is slowly dissolved by sulfuric acid.

Laboratory experiments on the rate of reaction were found to give results similar to those obtained on a large scale.

It is possible to foresee what measures are necessary for safe carriage of sulfuric acid in iron drums in any particular instance, if the conditions are known. The safety of carriage will depend on the quality of the acid, the size of the air space left when filling, the temperature, and the time that elapses before pressure is released.

With relatively dilute non-oxidizing acids, e. g. 1 N * H_2SO_4 and 1 N HCl, the rate of attack decreases with increased purity of the iron; pure iron dissolves slowly, gray and white cast iron and malleable iron dissolve fairly rapidly, and cast steel lies between the two classes.[7]

The rate at which wrought and cast iron are acted on by 0.2 normal sulfuric acid is shown in the following table,[7b] as are the analyses of the iron tested. The samples were cold hard rolled and polished; 1 square decimeter was exposed to the solution at a temperature of 17-20° C. In one set of experiments the pieces were exposed in ½ liter of solution for seven days, the solution being renewed each day; in the next set the exposure was for 28 days, the solution being unchanged; in the final set, the test pieces were immersed in one liter of solution for 4 hours.

ANALYSIS OF SAMPLES

	Per Cents			
Sample	Si	S	P	C
Cast iron..........	2.85	0.07	1.19	3.28
Wrought iron......	...	0.07	...	0.095

ACTION OF 0.2 N H_2SO_4 ON CAST AND WROUGHT IRON AT 17-20° C.

LOSS IN GRAMS PER SQUARE METER PER HOUR

Metal	7 days, ½ l. Acid Renewed Daily	28 days, ½ l. Acid Not Changed	4 hours, 1 l. Acid Not Changed
Cast Iron......	* 9.5	0.48	70.0
Wrought Iron..	* 10.1	0.49	8.75

* Estimated from results of less than 7 days' immersion.

The figures show that the reaction proceeds at a diminishing rate, and that this is probably due in part to a protective coating which is dissolved off with each successive change of the solution.

Burgess and Engle,[7a] however, take the position that purity is not the controlling factor in the corrosion of iron by 1 N H_2SO_4 and HCl. They found perfectly pure electrolytic iron to dissolve more rapidly than low carbon soft sheet iron, such as is used for transformer plates, or than ordinary cast iron. In fact, according to these authors, so readily does pure electrolytic iron dissolve in dilute sulfuric acid, that it has been suggested

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* See Appendix, p. 192.

RELATIVE RESISTIVITY TO N. H_2SO_4 OF VARIOUS FORMS OF IRON (BURGESS AND ENGLE)

Loss in Grams per Square Meter per Hour

Hours	1	2	3	4	5 *	6	7	8	9 †	10	11	Average
Electrolytic	49.5	455	624	634	796	745	663	654				578
Electrolytic Heated....	8.2	25.5	13.6	17.3	9.8	12.1	11.0	10.4	13.0	18.6	16.3	14.1
Cast Iron.............	117	147	114	57.3	51.2	81.4	98.9	90.1	103	105	130	99.6
Steel..................	26.3	13.3	109	183	176	151	183	213	208	176	217	150
Transformed Iron.....	13.9	21.1	4.3	10.8	13.0	12.6	15.0	16.3	16.6	17.3	18.5	14.4

---

* Added 3.1 g. H_2SO_4 per liter to replace that consumed by iron.
† " 4.6 g. " " " " " " " " "

in finely divided form as a substitute for zinc in the generation of hydrogen. Burgess and Engle's experiments led to the conclusion that crystalline or granular structure influences the rate of corrosion more than small percentages of impurities.

The table on page 31 gives the results of their experiments.

There has been a long and bitter controversy between the manufacturers of wrought iron and the manufacturers of steel as to the relative resistance to corrosion of the two metals, and various theories have been advanced.

The wrought iron makers have depended in the main on a theory of protective slag inclusions. According to this theory wrought iron owes its corrosion resisting properties to the fact that it contains from 4 to 6 per cent by volume of slag, distributed throughout the mass of metal in the form of fine filaments. Approximately several hundred thousand of these filaments exist in each square inch of metal section. Owing to the close formation of these slag filaments, the continued attacks of corrosion are greatly interfered with; in other words, the path of corrosion through the metal is constantly interrupted, greatly increasing the time necessary for penetration.[7c]

L. T. Richardson [7d] attempted to dispose definitely of the slag inclusion theory, and advanced a substitute theory based on the nitrogen content of the metal. The following table was introduced in the discussion in support of this idea. However, such a theory seems incapable of general application, and regardless of the possible explanations, the wrought iron manufacturers seem to have the facts on their side, as the superior corrosion resisting properties of wrought iron, especially in the form of pipe are commonly admitted.

ANALYSES OF ANCIENT IRONS

	Si	S	P	C	Mn	Cu	O	N	Cu, O, etc.	Fe
Iron pillar, Delhi, India (1600 years)	0.046	0.006	0.114	0.080	Nil	....	....	....	0.034	99.72
Rails from house at Dedham, Mass. (281 years)	0.029	0.009	0.005	0.015	0.020	0.016	0.060	0.005	....	99.841
Link from bridge at Newburyport, Mass. ..	0.028	0.014	0.023	0.040	0.008	Trace	0.027	0.003	....	99.867

The effect of impurities in sulfuric acid on its action on iron is most diverse. From Lunge's work (quoted above) there appears to be little difference between the action of pure and commercial strong sulfuric acid on cast iron, and the action of strong mixed acid (sulfuric and nitric) is in some cases less than that of either sulfuric or nitric acid alone. The presence of arsenic inhibits the action of sulfuric acid on iron to a marked degree, as has been proved in pickling practise. When the concentration of arsenic in pickling acid (H_2SO_4 60-66° Bé) reaches 0.003 per cent, the rate of solution of iron in it is approximately one-fifth of the rate in arsenic-free acid[12] owing to the formation of a protective coating on the surface of the iron. Niter cake ($NaHSO_4$) made from pyrites acid is said to be unusable for pickling because of its arsenic content, while that from brimstone acid may be successfully employed.

Alloy Steels.

Alloy steels containing somewhat large amounts of other metals are in some cases resistant to corrosion by acids, but until recent years no attempt has been made to use or market them industrially. In general it seems that the solid solutions of iron and the other metals are attacked, while the carbides remain unaffected. This has been shown in the case of the action of 10 per cent sulfuric acid on some alloy steels containing vanadium, chromium, tungsten, nickel, cobalt and manganese).[8] An early sample of a special alloy, described as "stainless steel" did not show satisfactory resistance to corrosion when tested with 10 per cent sulfuric acid;[11] its composition was:

C	0.3 %	Cr	12.7 %
Si	0.01	Co	0.45
Mn	0.12	Fe	86.6

On the other hand an alloy containing 9.18 per cent Cr and 0.71 per cent C was said to resist corrosion very well.

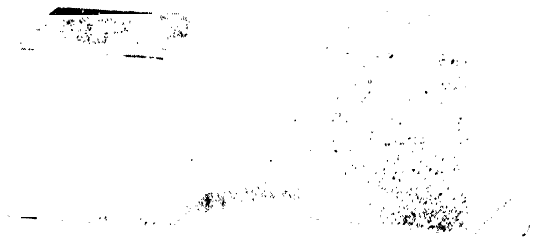
Chemically resistant high-chromium steels have, however, been more thoroughly studied and much developed in the last two or three years, and are finding constantly wider application in many fields, as for example in cutlery and surgical and dental instruments. The standard composition of "Stainless Steel" is stated to be:

	Per Cent
C	0.20-0.40
Cr	11.40-14.00
Mn	less than 0.50
Si	" " 0.30
P and S	as low as possible

Properly hardened this steel has a martensitic structure with numerous globules of double Fe-Cr carbides, and its hardness varies as the carbon content.[9] Cold working destroys its stainless properties, and heat treatment is necessary to restore them. Its coefficient of expansion is 1.0915×10^{-5}.

A steel has been placed on the market under the trade name "Chemi-Steel" designed to meet the requirements for the construction of chemical apparatus.[10] Its composition is not given, but the results of tests are reported in which this steel is compared with the best gray cast iron. With both 93 per cent and 77 per cent sulfuric acid the steel showed less pitting and loss of weight on many hours' immersion at temperatures up to 70° than did the cast iron. With the weaker acid its average loss was between ⅓ and ¼ that of the cast iron.

Another steel of interesting characteristics and unstated composition was recently produced by the Crucible Steel Company of America in the effort to develop a heat resisting steel of high melting point.[9a] The product not only has this quality, but is also non-magnetic and resistant to rusting and attack by acids. If heated to 700° C., it becomes susceptible to magnetic attraction, but can be returned to the non-magnetic state by heating five or ten minutes at 870° C. and subsequently cooling in the air. It is tough and strong at all temperatures from — 185° C. to 1300° C., and has an extraordinarily high reduction and elongation at temperatures that would burn anything but high speed steels. It is made in grades designated as 2, 3, 4 and 5.



Chemi-Steel Cast Iron

93 Per Cent H_2SO_4

Chemi-Steel Cast Iron

Courtesy The M. W. Kellogg Company

77 Per Cent H_2SO_4

Fig. 2.—Comparison of Effect of Concentrated and Dilute Sulfuric Acid on "Chemi-Steel."

The resistance of this steel to sulfuric acid as compared with other metals and alloys is given in the following table; the results have been recalculated into terms of loss in grams per square meter, but as no time data have been given, the more general unit of grams per square meter per hour cannot be used; temperature data are also lacking.

ACTION OF SULFURIC ACID

Loss in Grams per Square Meter

	10 Per Cent H_2SO_4	32 Per Cent H_2SO_4
Crucible steel, grade 4·2	5.0	5.1
“ “ “ 3·2	8.4	9.8
High Cr, Ni steel	175	1619
“ Cr, Si “	...	3378
25 per cent Ni	17.0	13.9
Wrought iron	759	1739
Copper steel	113.7	149
Monel metal	2.0	1.9
High Cr steel	1956	3194

After suitable heat treating and annealing the steel can be machined, drilled or milled with high speed tools.

Oliver P. Watts [12a] directs attention to another phase of the protective action of arsenic on the rate of corrosion of iron by sulfuric acid. It had long been considered an impossible task to deposit electrolytically a thin coating of one metal upon another so perfectly as to properly protect the underlying metal from acid corrosion. Arsenic was found to protect iron almost completely and it was thought that the explanation lay in a high overvoltage, or excess potential, of hydrogen on arsenic. Experiments were carried out to verify this theory. The specimens were immersed in acid and suitable reagents added. Dilute sulfuric acid ordinarily dissolves iron many times as actively as does hydrochloric acid. The substitution of 10 cc. hydrochloric acid for an equal volume of water reduced the sulphuric acid corrosion to less than one-half that of hydrochloric acid. Temperature control was also an important factor in reduction of corrosion by sulfuric acid. Very little corrosion took place in the presence of arsenic, and tin also was an excellent protective. Experiments were carried out with other reagents and the results are given in the following table:

Retarders of Corrosion.

Acid, hydrobromic
“ hydrochloric
“ hydrofluoric
Sodium arsenate
Arsenic sulfate
Potassium bromide
Ammonium chloride
Manganese “
Mercury “
Sodium “
Tin “

Chrome Alum
Chromium sulfate
Potassium fluoride
Hydroquinone
Potassium iodide
Mercury chloride
“ sulfate
Resorcine
Sodium stannate

Accelerators of Corrosion.

Acid, chromic
Bismuth sulfate
Cromium chloride
Copper sulfate
Gold chloride
Mercurous nitrate
Platinum chloride
Potassium chlorate
“ chromate
“ dichromate
“ nitrate
“ permanganate
Silver nitrate
“ sulfate

Of No Effect or Doubtful.

Acid, boric
“ citric
Ammonium sulfate
Antimony sulfate
Potassium sulfate

It was further brought out:

(a) If sheet iron be immersed in dilute sulfuric acid containing a small quantity of arsenic the solution of the metal is retarded. If, on the other hand, a small quantity of arsenic be alloyed with iron and the iron rolled into sheet form its solubility is accelerated. With copper the reverse is true.

(b) A sample of steel containing 0.2 per cent copper was immersed in sulfuric acid as was a sample of poor, copper-free steel. In 20 per cent acid the copper-steel was 50 times as good as the other, but in 1 per cent acid the ratio between the two steels was only three instead of fifty.

(c) The samples containing arsenic were more resistant to atmospheric oxidation and to corrosion by very dilute acid than the original iron.

Ferro-silicon Alloys.

The commercial development of acid-resisting ferro-silicon alloys is one of the most important new phases of chemical engineering, and has, in fact, revolutionized many manufacturing processes. With all their drawbacks, such as brittleness, difficulty of machining and of casting, they hold an assured place today, and enable the manufacturer not only greatly to reduce replacements in handling corrosive liquids, but to carry out processes on a scale and in a way not possible before.

Most of this class of materials are sold under product trade names. Some of the better known brands and the countries of their origin are: Duriron and Corrosiron, United States; Ironac, Tantiron, England; Métillure, France; Elianite, Italy; Neutraleisen, Germany. The chief characteristic of all of these is a silicon content of about 13-15 per cent. Analyses of these products, quoted from various sources, are:

	Duriron[13][15]	Ironac[14]	Tantiron[13]	Elianite[14]	Cast Iron[10]
Si..........	14.0-14.5	13.5	14.0-15.0	14.8	
S..........	Less than 0.05	....	0.05-0.15	....	
P..........	0.16-0.20	0.7	....	0.0	
C..........	0.20-0.60	2.7	0.75-1.25 *	1.1	
Cu..........	....	Trace	....	0.0	
Fe..........	....	82.5	....	83.1	
Mn..........	0.25-0.35	Trace	2.00-2.50	0.0	
Melting point	1370-1400° 1387°	....	1232°	....	
Specific gravity	7.00	....	6.8	....	
Tensile strength	25% less than cast iron 5-6 tons per sq. in.	....	6-7 tons per superficial inch	....	6-9 tons per sq. in.

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* Graphitic only.

Another authority states that Tantiron contains about 12 per cent silicon and 4-6 per cent aluminum.[17]

The heat conductivity of this alloy is twice that of lead and four to five times that of stoneware or quartz.[20]

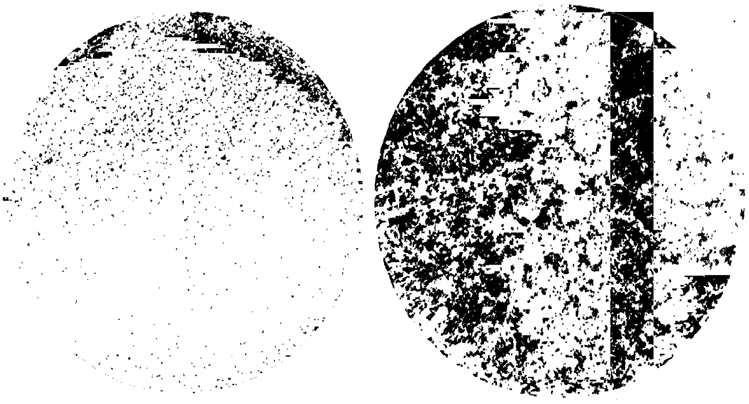
The interesting feature of these alloys is the silicon, which is at once the disturbing and absolutely necessary element, responsible both for brittleness and resistance to acids. The effect of variations in its amount is shown in the following table:[18]

ACTION OF 10% SULFURIC ACID ON FERRO-SILICON ALLOYS

		Cumulative Loss		
Si %	Area, cm^2	51 Hrs.	75 Hrs.	141 Hrs.
2.5	15.7	1.6	4.1	6.5
3.3	21.9	64.9	87.5	92.8
7.4	11.5	31.0	48.0	62.0
9.9	12.7	10.7	19.8	23.1
11.1	13.0	5.0	8.8	13.1
12.4	9.2	1.2	2.1	2.4
13.6	16.6	0.2	0.6	0.9
14.8	18.0	0.03	0.05	0.05
16.1	10.2	0.03	0.04	0.04
17.3	11.9	0.03	0.03	0.03
19.8	9.6	0.13	0.2	0.25

Although exceedingly interesting for the immediate purpose in view—the study of the effect of varying the amount of silicon in the alloys in question—it is unfortunate that the precise conditions of the experiments were not given; the blame for this omission cannot, however, be laid to the original author, since the tables were quoted second hand. The figures show that while iron with 2.5 per cent silicon is somewhat resistant to sulfuric acid for a limited time, the addition of more silicon makes it less so. As the silicon content reaches 12 per cent, the resistance of the metal becomes very marked, and continues so up to a 20 per cent content, at which point it again begins to diminish slightly. The minimum action takes place with iron of a 15 per cent silicon content.

While the alloys of less than 10 per cent silicon content are not exceedingly brittle, they are readily attacked by all acids; the resistant alloys with 16-18 per cent silicon are so brittle that it is almost impossible to machine them, but they may be accurately ground. These alloys are also difficult to cast, and it was the solution of the foundry problems involved that made them available for industrial purposes.



Left x 2¼. Right x 40.

FIG. 3.—Duriron Hardly Affected by Action of 6 Per Cent H_2SO_4 at 90 to 100° C.

The manufacturers of various brands of ferro-silicon alloys have given out many data as to acid-resisting qualities, but unfortunately many of these are presented in such form that they are of significance only among themselves, as showing the relative reactivity of the alloy with different acids, or the variation in the rate of solution with the time.

The manufacturers of Tantiron state that on boiling 100 g. of this material for 17 hours with 10 per cent sulfuric acid, 0.13 g. were dissolved, and show the progress of such a reaction in the following table:

LOSS OF WEIGHT OF TANTIRON[19]

Acid Used	Loss, First 24 H.	Second 24 H.	Third 24 H.
Sulfuric acid			
98%..........	0.10	0.02	0.02
30%..........	0.07	....	....

The loss is presumably expressed in grams. Duriron is stated by its manufacturers[18] to have sustained no loss in contact with 25 per cent sulfuric acid for one year.

Later and more precise figures from the same source[21] are the following:

ACTION OF SULFURIC ACID ON DURIRON

Strength of Acid	Temperature	Duration of Test	Loss in g. per m² per Hr.
28% by vol. (38% by wt.)....	room temp.	one year	0.0025
" " " " " "....	80°-85°	five weeks	0.0588

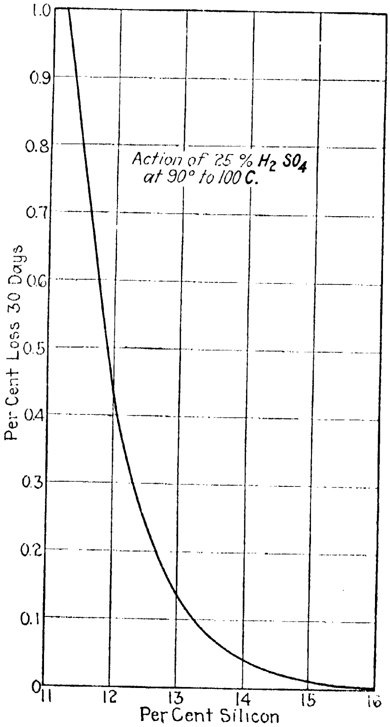


FIG. 4.—Action of 25 Per Cent H_2SO_4 at 90 to 100° C. on Duriron.

Of two samples of soft lead, the purer was found to be decidedly the better; even a very small amount of bismuth (0.044 per cent) was detrimental.

It is impossible to measure the resistance of lead to sulfuric acid by measuring the gas evolved in the reaction, since the gas from the reaction with hard lead is far less than the simple equation calls for. For this reason lead-lined containers, if sealed, should be lined with hard lead.

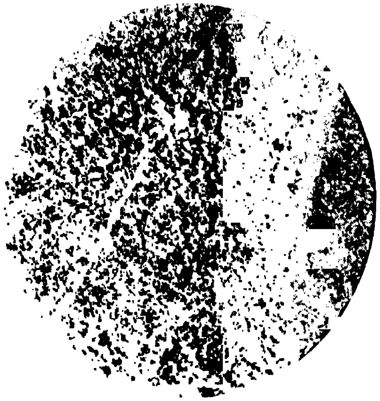


FIG. 5.—Chemical Sheet Lead (x 40) After Exposure to 6 Per Cent H_2SO_4 for a Long Period at Ordinary Temperatures.

Effect of Nitrous Sulfuric Acid.

Nitrosyl sulfuric acid, $HNSO_5$, is present in nitrous sulfuric acid containing 0.1 per cent N_2O_3, if the sulfuric acid is of a concentration greater than that corresponding to s. g. 1.768. If the acid is diluted beyond this point, $HNSO_5$ is hydrolyzed to nitrous and sulfuric acids:

$$HNSO_5 + H_2O \longrightarrow HNO_2 + H_2SO_4.$$

Concentrated sulfuric acid containing N_2O_3 always acts on lead more vigorously than the pure acid, but in the case of acids of lower strength (s. g. 1.72-1.76), that containing nitrous acid acts less on both hard and soft lead; at greater dilutions, the conditions are again reversed. In all cases nitrous sulfuric acid acts more in the presence than in the absence of air. The minimum action of such acids on lead is at concentrations corresponding to s. g. 1.5-1.6.

Effect of Concentration.

At the higher concentrations of acid the rate of action on lead increases very fast. Technical "monohydrate" (98.85 per cent H_2SO_4), for example, attacks lead 13.5 times as fast as ordinary concentrated acid, 96.5 per cent. Fuming sulfuric acid acts still more vigorously, and when it has a content of 20 per cent free SO_3, it acts 32 times as fast as ordinary concentrated acid.

Other Factors.

The oxygen content of lead is always low and seems to have little bearing on its resistance to acids.

When the density of the surface of lead is mechanically increased, its resistance to acid is increased.

For sulfuric acid chambers and other apparatus where the temperature is moderate, it may be concluded from the foregoing generalizations that the purest soft lead is to be preferred, for it is least acted on by hot sulfuric acid, whether dilute or concentrated, pure or nitrous. Any sensible amount of antimony is

ACTION OF SULFURIC ACID ON LEAD

Loss in Weight in Grams per Square Meter per Hour

			ACID		
Kind of Lead	Time	Temperature	Pure S.g. 1.84	Nitrous No air	Nitrous In air
Soft Lead I.....	8 days	Ordinary	0.667	0.831	0.979
Hard "	"	"	0.662	0.844	0.990
Antimony Lead..	"	"	0.776	1.042	1.190
Soft Lead I.....	6 hours	100°	14.5	15.2	17.7
Hard "	"	"	50.7	68.5	77.4
Antimony Lead..	"	"	32.3	57.6	63.3
Soft Lead I.....	3 hours	200°	92.5	87.0	142.8
Hard "	"	"	1277	1158	1292
Antimony Lead..	"	"	800	1175	1327
			Pure s.g. 1.725	Nitrous No air	Nitrous In air
Soft Lead I.....	6 hours	100°	7.83	5.16	6.23
Hard "	"	"	8.13	7.86	7 71
Antimony Lead..	"	"	8.75	13.13	12.75
				Nitrous	
Soft Lead II....	30 days	Ordinary	0.483	1.475	
Soft Lead 0.2% Cu............	"	"	0.404	1.428	
Soft Lead II....	10 hours	100°	7.91	7.97	
Soft Lead 0.2% Cu............	"	"	8.01	8.31	
Soft Lead II....	10 hours	200°	60.14	61.53	
Soft Lead 0.2% Cu............	"	"	49.61	65.24	

Note.—The nitrous acids were prepared from the pure acids, dilute and concentrated, by adding chamber crystals sufficient to make the N_2O_3 content 1 per cent.

COMPOSITION OF LEADS TESTED

	Soft Lead I	Soft Lead II	Hard Lead	Antimony Lead
Copper	0.001	0.0034	0.05	0.1-0.3
Bismuth	0.044	0.0019	0.01	......
Antimony	0.0004	0.0029	1.81	18.1-18.3
Arsenic	0	0.0047	0.10	1.0-3.1
Iron	0.0005	Trace	0.01	......
Cadmium	......	0.00025	....	......
Silver	0.0005	0.0010	....	......
Tin	0.0004	......	0.04	0.1
Zinc	......	0.0002	....	......
Oxygen	......	0.0024	....	......

nearly always injurious, and copper is in most cases no improvement. Where temperatures are high (above 200° C.), the presence of 0.1-0.2 per cent copper is an advantage, and in the presence of bismuth it protects the lead from the sudden destruction sometimes observed.

The order of magnitude of the actions discussed is shown by the foregoing excerpts from the tables of Lunge and Schmid, in which the results have been recalculated to grams of lead dissolved per square meter per hour.

Lunge considers soft leads I and II "specially suited for vitriol chambers" (loc. cit.).

The fact, noted by Lunge and Schmid (loc. cit.), that lead of varying degrees of purity, when heated with concentrated sulfuric acid, decomposed the acid violently at different temperatures, has been proposed as a test for lead intended for use as an acid-resisting material, so-called "chemical lead"[21] A piece of sheet lead one inch square is heated in concentrated sulfuric acid, which is stirred meanwhile with a thermometer. With a good grade of chemical lead the violent reaction with an evolution of gas does not set in below 220-240°; with poor lead it starts at 180° or lower.

A recent study[8] has been made of this sudden reaction of lead with sulfuric acid when the lead has been alloyed with various elements. Four samples of lead of the following composition were studied. The temperature of attack in the following table is the temperature at which action is vigorous:

	Sample			
	1	2	3	4
Cu	0.002	0.021	0.017	0.017
Bi	Trace	0.005	0.004	0.001
Ag	0.001	0.002	0.002	0.002
As	0.001	Trace	Trace	0.001
SB	0.009	0.003	Trace	0.301
Fe	0.005	0.004	0.003	0.003
Mn	Trace	0.001	0.001	0.001
Zn	0.001	0.001	0.001	Trace
Pb (by difference)	99.981	99.963	99.972	99.674
Attacked vigorously by H_2SO_4 at	250°	296°	300°	260°

Leads 2, 3 and 4 contain more copper than 1, and lead 4 contains comparatively a great deal of antimony.

A series of alloys was made with lead 1 and tested with concentrated sulfuric acid. "First action" is the first appearance of a regular stream of bubbles; "vigorous action" is stormy frothing.

	First Action	Vigorous Action
Lead 1 alone	150°	220°
" and 0.2% Cu	210	315
" " " Bi	70	135
" " " As	213	260
" " " Sb	150	220
" " " Zn	160	200
" " " Sn	156	232
" " " Ag	200	262
" " " Te	190	316
" " " S	142	238

The heat refining of commercial lead will give a product resisting attack up to 280°, and the purest electrolytic lead (99.998 per cent Pb) withstands action up to 310°. Leads not of the highest purity are rendered more resistant by the addition of a small amount of copper, which is, as has been said, in general advisable for industrial work at high temperatures.

Because of its acid resistant characteristics lead is extensively used as a lining not only for wooden chambers and tanks, but for metal, chiefly iron, tanks, stills, pipes, etc. The lining may be simply fitted to the vessel (which is usually the case with the larger sizes), or the surface may be "homogeneously leaded" (as is usually the case with pipes) either under pressure or by coating with molten lead through the aid of a proper flux.

Quantitative results are also available on the action of very dilute sulfuric acid on lead,[9] though, unfortunately, the analytical data are not as extensive as could be wished. The lead tested contained a trace of silver and no zinc. The tests were made as follows:

A sample of the polished, cold hard rolled metal, with a total area of 1 square decimeter, was immersed in 0.2 N (approximately 1 per cent) sulfuric acid at a temperature of 17-20°. In experiment 1 the amount of acid was 500 c.c., the acid was renewed each day, and the immersion lasted 7 days; in 2 the immersion was in 1000 c.c. for 4 hours; in 3 the lead was kept in 500 c.c. acid for 28 days, and the acid was not renewed.

The results given here have been recalculated in terms of loss in grams per square meter per hour.

Experiment	Duration	Loss in $g/m^2/hr$
1	7 days	0.0059
2	4 hours	No weighable loss
3	28 days	0.0030

The total weights of lead dissolved in experiments 1 and [illegible] were respectively 0.01 and 0.02 g.

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III. Sulfuric Acid and Other Metals.

In the main, sulfuric acid at low temperatures and dilute acts towards metals very much as would be predicted from their position in the electromotive series;* its hydrogens are replaced by metals more electropositive than hydrogen, and it is inert towards metals more electronegative than hydrogen. At low temperatures it is not a very vigorous oxidizing agent, as was pointed out in Section I of this chapter, but at high temperatures and at high concentration its behavior is quite different; under these conditions it is a strong oxidizing agent, and vigorously attacks many metals, being itself decomposed to H_2S, SO_2 and other products.

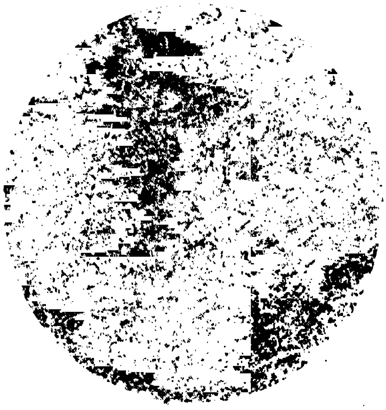

FIG. 6.—Copper (x 40) after Exposure to 6 Per Cent H_2SO_4 at about 80° C. for a Long Period without Agitation.

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* The common metals arranged from the most to the least positive: K Na Ba Sr Ca Mg Al Mn Zn Cr Cd Fe Co Ni Sn Pb H As Cu Sb Bi Hg Ag Pd Pt Au.

An example of the different reactions taking place between metals and sulfuric acid of different strengths is given by the behavior of sulfuric acid towards zinc.[1] At concentrations from H_2SO_4 (100 per cent) to $H_2SO_4.5H_2O$ (52 per cent) the gaseous products of the reaction are H_2S and H_2; with $H_2SO_4.6H_2O$ (48 per cent) the only gaseous product is H_2. In the former case the metal is oxidized and the acid molecule completely broken up; in the latter the hydrogen is simply replaced by the metal, or, more precisely, the positively charged hydrogen ion has transferred its charge to the metal and escaped as a gas, the metal dissolving as an ion.

The presence or absence of the oxygen of the air makes a great difference in some cases. With some metals under conditions of temperature and concentration where no action would take place with sulfuric acid alone, the presence of air will cause the metal to be attacked.

Platinum and Gold.

Before the development of acid-resistant fused silica and ferrosilicon apparatus platinum, gold and noble metal alloys were used in the construction of stills, condensers and other parts of plants used for the manufacture of pure sulfuric acid. For this reason the action of sulfuric acid on these materials has been studied in some detail.

Pure sulfuric acid[2] has little action on platinum even at the boiling point, and scarcely any at lower temperatures, but the action is increased by certain impurities in the platinum and others in the acid. Some acid impurities, however, tend to inhibit the solution of the metal: e. g., carbon, As_2O_3, S, SO_2.[3] The rate of the action of sulfuric acid on platinum is shown by a test in which 95 per cent sulfuric acid dissolved 40 mg. from a piece of platinum foil 13.4 x 5.25 cm. in 28 hours at 250°, or 0.0102 g. per sq. m. per hour.[3] The rate of solution seems more dependent on the temperature than on the concentration of acid.

When sulfuric acid is concentrated in platinum pans, the usual losses are from 0.18-0.78 g. for 92 per cent acid to 1.9-3.0 g. for 97 per cent acid per ton of acid concentrated, though they occasionally run as high as 20 g. per ton.[4]

Since certain reducing substances in the acid reduce its action on platinum, it is not surprising to find that oxidizing substances like persulfates, dichromates, permanganates or chlorates have the opposite effect. Even dilute sulfuric acid at ordinary temperatures containing one of these substances sensibly dissolves platinum.[5] Hydrogen peroxide in sulfuric acid, however, though it increases its action on some metals, does not cause the dilute acid to dissolve platinum appreciably.[6]

Not all impurities or foreign substances in the metal cause platinum to be attacked more rapidly by sulfuric acid. An alloy of 90 parts Platinum and 10 parts Iridium on boiling 40 days with sulfuric acid lost only ½ as much as pure platinum, and a 95:5 alloy lost ¾ as much.[7] On the other hand the advantage of the 90:10 alloy over pure platinum is said to decrease after the first 8-10 hours' boiling.[8]

The action of hot concentrated sulfuric acid on gold is less than that on platinum. The use of gold in acid-manufacturing apparatus instead of platinum is controlled by the relative cost of the two metals and the greater softness of gold. When gold cost more than platinum, platinum stills were sometimes lined with gold. The losses of gold per ton of acid concentrated were:

Strength of Acid	92%	93-96%	96-97%	97-98%
Loss	0.011-0.072 g	0.03-0.138 g	0.17-0.205 g	0.040-0.26 g

An alloy of 90 parts gold and 10 parts platinum is satisfactory for acid concentration in every respect; it is sufficiently hard and can be soldered with pure gold.[4]

Base Metals.

The rate of solution of iron and lead in 0.2 N H_2SO_4 has been given above (pp. 22 et seq. and 43); figures for some other metals are given below. Of these metals zinc, aluminum, tin and nickel are more electropositive than hydrogen and copper less so. From the extent of the action of the acid on copper it appears that the experiments must have been carried out with free access of air, the influence of which was mentioned above. The constituents determined by analysis in the five metals tested are given in the table that follows:

	Zinc	Aluminum	Copper	Tin	Nickel
Si	.....	0.23	.....	.....	0.20
Pb......	110	.....	0.15	0.61	.....
Cu......	.....	Trace	.....	Trace	0.16
Bi	.....	.....	0.03	.....	.....
As......	Trace	.....	.....	Trace	.....
Fe......	0.055	0.28	Trace	0.014	0.46
Zn......	.....	.....	.....	0.15	.....
Na	.....	0.05	.....	.....	.....

The conditions of the test were as follows: Sheets of the metals, cold hard rolled and polished, each of a total area of one square decimeter, were immersed in 0.2 normal sulfuric acid at 17-20°. In the first series, results of which are given in column one of the table below, the amount of acid was ½ liter and it was renewed daily for 7 days; in the second series, column two, one liter of acid was used and the action continued for 4 hours; in the third series, column three, ½ liter of acid was used but not renewed, the action continuing for 28 days.

THE ACTION OF 0.2 N H_2SO_4 ON METALS AT 17–20°

LOSS IN GRAMS PER SQUARE METER PER HOUR

	7 Days Acid Renewed Daily	4 Hours Acid Not Changed	28 Days Acid Not Changed
Zinc	* 13.1	100	0.446
Aluminum	0.536	1.25	0.042
Lead	0.006	0.00	0.003
Copper	0.149	0.59	0.067
Tin	0.131	0.50	0.037
Nickel	0.149	0.50	0.059

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* Estimated on the basis of action lasting less than 7 days.

It is to be noted that in all cases (except that of lead in column two, where the total in 4 hours was probably not weighable) the rate of solution diminishes greatly with increase of the time of action.[9]

Although zinc is a strongly electropositive metal, perfectly pure zinc is said to be unattacked by sulfuric acid weaker than 0.5-1.0 normal.[10] Arsenic, lead and cadmium cause no quicker solution of zinc, but as little as 0.01 per cent nickel, platinum or gold appreciably increase the rate.

Just as the presence of air in some cases is responsible for the action of otherwise comparatively inert acids on metals less electropositive than hydrogen, so the presence of oxidizing substances in the acids, as has been mentioned, often has the same effect. Dilute sulfuric acid containing hydrogen peroxide dissolves copper, silver, nickel and bismuth, but not tin, lead, gold or platinum. The solubility of aluminum is not affected by the presence of hydrogen peroxide.[6] It may be well, however, to point out here that for practical purposes the question of the velocity of solution of a metal is the important one, rather than the question of whether or not there is any measurable action at all. Practically the solution of a metal in an acid may be neglected if its velocity is extremely small. Other factors than the position of the metal in the electromotive series, such as the formation of protective coatings, affect the reactions, so that the series serves only as a general guide under restricted conditions.

Of the metals more electropositive than hydrogen lead (see above), aluminum,[11] cobalt and nickel react very slowly with sulfuric acid; in the case of aluminum the hydrolysis of the aluminum sulfate produced forms a protective coating of aluminum hydroxide or basic aluminum salts on the surface of the metal.

Bronzes and Other Alloys.

In order to prepare metals of various special characteristics or combinations of characteristics, such as hardness, ductility, thermal expansion, tensile strength, etc., innumerable alloys have been made and experimented with; some, like brass, have been in common use for centuries. Among the properties aimed at has been resistance to chemical action.

Chemically resistant alloys may in general be divided into two classes: First, that in which the metal is the important consideration. Here a moderate amount of action under the conditions of use is not a fatal objection provided it is not great enough to cause a rapid deterioration of the metal. An example of this is metal apparatus, as for example overhead electric wires, in places exposed to corrosive fumes; while absolute chemical inertness would be an advantage, it is not a necessity, since the metal may have a long period of usefulness after considerable corrosion has occurred. The second class is that in which the material contained or handled in the metal is the important factor. In such cases the allowable limits of action are usually much narrower; the action must be so slight that no appreciable traces of dissolved metal occur in the material handled. An example of this is an acid solution in an acid-proof tank of a dye whose shade would be affected by ferrous salts. Here an amount of chemical action less than would destroy the tank in long use would nevertheless be deleterious to the product handled. These two classes obviously shade into one another, and depend as much on the use made of the materials as on the materials themselves. Hence no effort will be made to classify acid resistant alloys in themselves according to the above scheme.

Two of the more recent alloys that have come into considerable use are known under the names of Monel Metal and Nichrome.

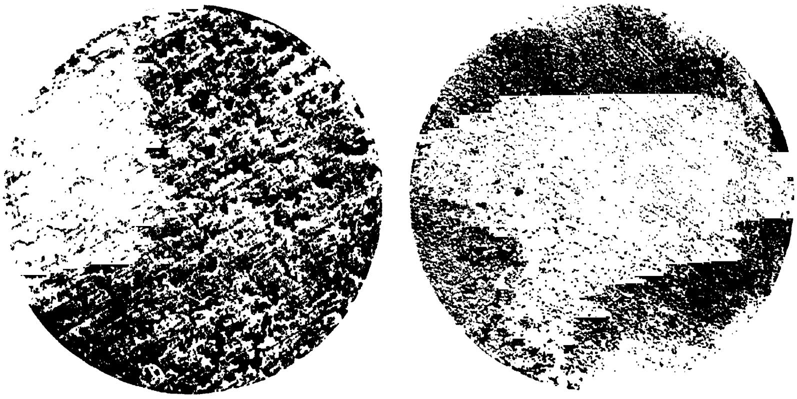
Monel metal[12] was introduced by the International Nickel Company about 1905 and named after its then president, Ambrose Monell. It is a natural alloy produced directly from Canadian bessemer matte by roasting and reducing with charcoal and has the following average composition: nickel, 67 per cent; copper, 28 per cent; other metals (iron, manganese, silicon), 5 per cent.

Several grades of this metal are produced for different purposes of which the following typical analyses are given:

	Per Cent				
	C	Mn	Fe	Si	S
Rolled Monel metal sheet	0.11	0.15	1.76	0.18	0.026
Rolled Monel metal rods	0.26	1.78	2.00	0.20	0.035
Monel metal wire	0.12	1.66	2.10	0.13	0.025
Monel metal castings	0.18	0.25	1.90	1.06	0.03

It will be noted that the wire is made with low carbon content in order that it may be readily cold-drawn, whereas hot-rolled rods are produced with somewhat more carbon in order to increase the ease of hot-rolling.

Monel metal resists the action of sulfuric acid fairly well and one of its principal applications is in the construction of tanks and crates for pickling steel; rods are used for this purpose and have apparently proved superior to any other material. In this connection the results of corrosion tests of Monel metal rod in pickling acid are of interest. Rods exposed for ninety days to the action of continually renewed 6° Bé. (6 to 7 per cent) sulfuric acid at 74° C. lost weight at the average rate of 0.0045 g. per sq. in. per day, corresponding to the removal of a layer 0.00003 in. thick per day; the removal of a 0.1 in. layer would therefore require about ten years. In fact Monel metal pickle-pins and pickle-rods have been removed from service after eight years and were found to show practically no evidence of corrosion. Their average life is perhaps three years. On account of its resistance to corrosion the metal is also used in the construction of mining machinery, mine screens, dyeing machinery and equipment and in the chemical and oil industries for miscellaneous parts exposed to severely corrosive conditions.[12, 13]



Monel x 40. Acid Resisting Alloy x 40.

FIG. 7.—Comparison of Corrosion of Monel Metal (Left) and an Inferior Acid Resisting Alloy (Right). The Corrosion of the Monel Metal is Uniform; of the Other Metal "Spotty" Owing to Spongy Areas Opened Up by the Acid. Corroding Agent 6 Per Cent H_2SO_4 at about 80° C.

Nichrome (Driver-Harris Company), as its name indicates, is an alloy of nickel and chromium. At high temperature a non-flaking, protective coating of oxide forms on its surface. It is fairly resistant to all strengths of sulfuric acid, and since it can be cast and drawn, it is excellent for metal laboratory apparatus such as crucible tongs, wire gauze, etc.,[14] as well as for larger objects.

The rate of action of sulfuric acid on nichrome is shown in the following table:

ACTION OF SULFURIC ACID ON NICHROME

		Loss in g/m²/hr During the Periods			
Strength of Acid	Temp.	0–48 hr	48–72 hr	72–142 hr	0–142 hr
Concentrated (94%)...	25°	0.334	0.588	0.261	0.341
Dilute, 4 M (39%).....	"	0.121	0.061	0.005	0.077

		Loss in g/m²/hr in 4 Hours
Concentrated (94%)...	95–98°	7.14
Dilute, 4 M (39%).....	"	1.95

An alloy containing an unusually large number of constituents has been empirically developed[17] as an acid and corrosion proof material. Its composition is:

	Per Cent		Per Cent
Cu	6.42	Al	1.09
Mn..........	0.98	Fe	0.76
Si	1.04	Cr	21.07
W	2.13	Mo..........	4.67
Ni	60.65		

The alloy is resistant to sulfuric acid. It is difficult to cast, but turns well. Its tensile strength is about 50,000 lbs. per sq. in.

"Stellite" is an alloy of increasing commercial importance that has interesting characteristics. It is exceedingly hard, its scleroscopic number being 90 as compared with 80 for tool steel; it is brittle but can be used for tools if given proper support, and it can be welded to carbon steel shanks. Its composition is

Co......... ..	50–60%
Cr...........	30–40
W...........	8–20

In a series of tests made at Purdue University its behavior with 25 per cent sulfuric acid is described as follows:

ACTION OF 25 PER CENT SULFURIC ACID ON STELLITE

Material Tested	Action
Cast festel stellite..........................	Corroded, loss 0.61 per cent
Hammered festel stellite.....................	Corroded, loss 0.35 per cent
Cast soft malleable stellite..................	Very slightly tarnished, loss negligible
Hammered soft malleable stellite............	Slight tarnish
Cast hard malleable stellite..................	Slight tarnish
Hammered hard malleable stellite...........	Slight tarnish
No. 2 stellite..............................	Tarnished in spots
No. 3 stellite..............................	Tarnished in spots
No. 4 stellite..............................	Very slightly tarnished

Reactions intensified when reagent is boiled.[15]

Still another alloy containing nickel and chromium and resistant to sulfuric acid has the composition:[18]

	Per Cent
Fe..............	30–70
Ni..............	25–50
Cr..............	5–20

It can be drawn and rolled.

The addition of chromium alone to iron increases its tendency to dissolve in sulfuric acid.[19]

Neither pure silver nor its alloy with 16.5 per cent copper (Italian coin metal) is attacked by pure boiling sulfuric acid up to 60° Bé., but even 2-3° Bé. acid containing nitric, nitrous or hydrochloric acid dissolves out silver from the alloy. Sulfuric acid of 45-50° Bé. containing 1 c.c. concentrated nitric acid per liter attacks silver.[20]

An acid-proof bronze is reported containing [21]

Cu................	15 parts
Zn................	2.34 "
Pb................	1.82 "
Sb................	1.1 "

A chromium-copper-nickel alloy is also stated to be very resistant to acids.[16]

Another resistant alloy put out under the trade name of "Meco" is said to withstand the action of both sulfuric and hydrochloric acids: [22]

Acid	Temperature	Time	Loss in g. per m²	Loss in g. per m² per hour
25% H_2SO_4.........	90–100°	48 hours	7.3	0.15
" "	15–20°	30 days	7.7	0.011

Reported tests indicate that the alloy is more resistant to various acids than is bronze, brass or lead.

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III. Other Acids and Metals.

Nitric Acid.

Nitric acid, besides being a strong acid, is a vigorous oxidizing agent. Commercial nitric acid, dilute and concentrated, and the ordinary pure laboratory acid through a wide range of concentrations attack almost all metals except the noble metals, which are very unreactive in general, and aluminum, on which it forms an insoluble protective coating of oxide. Being a strong oxidizing agent, it is itself reduced by the metal acted on. For example the reaction with copper is:[1]

$$8HNO_3 + 3Cu \longrightarrow 4H_2O + 2NO + 3Cu(NO_3)_2$$

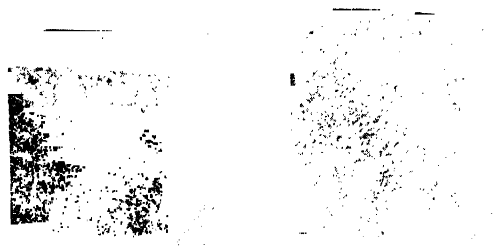
A most surprising fact about the behavior of nitric acid is, however, that if it is perfectly pure and free from nitrous acid, HNO_2, it does not react with metals as does the ordinary acid, which always contains traces of nitrous acid.[2] Nitric acid free from nitrous acid, of 30 per cent strength, at room temperature does not dissolve pure copper, mercury, bismuth, silver, cadmium, zinc or iron, but the addition of a small amount of nitrous acid causes a vigorous action.

Metallic lead is attacked to a slight extent by both concentrated and dilute pure nitric acid as well as by nitrous acid (0.158 g. HNO_2 per 15 c.c.), and by both together to an even greater extent. As far as the concentration of nitric acid goes, the maximum action takes place with a 29 per cent solution, which dissolves the lead at the rate of 1400 g. per m.^{2} per hour, the nitrous acid content in this case being about 0.05 mg. per c.c. The addition of oxidizing substances which would tend to prevent the formation of nitrous acid, such as $KClO_3$ and H_2O_2, does not prevent the solution of the lead, but makes it slower. As in the case of sulfuric acid, pure lead is in general less readily attacked than lead containing 5-10 per cent antimony.

"Nitric acid" as used in what follows will mean commercial or laboratory acid containing a small amount of nitrous acid unless the contrary is specified.

Iron.—Dilute nitric acid reacts strongly with iron, but concentrated acid more slowly. The addition of a small amount of sulfuric acid tends to prevent this action, permitting the acid to be shipped in steel drums or tank cars. "Mixed acid," that is, a mixture of concentrated sulfuric and nitric acids used in nitrating organic compounds, can also be handled in iron and steel.

Just as fuming sulfuric acid, though not dissolving cast iron to any considerable extent, may cause an explosive cracking of cast iron vessels (see above), so a very similar action of mixed acid resulting in an accident has been reported recently.[3] Two cast iron acid eggs filled with mixed acid used in the manufacture of trinitrotoluol burst under a pressure of 50 pounds per square inch. Superficial examination showed little corrosion, but photomicrographs indicated that the acid had penetrated the metal to one third of its thickness (1-1½ inches) and formed small clusters of crystals of ferric salts. It is supposed that the expansive force of the growth of these crystals ruptured the iron, and the conclusion is obvious that it is dangerous to use cast iron with nitric acid as it is with oleum.



Chemi Steel　　Cast Iron

Courtesy The M. W. Kellogg Company

FIG. 8.—Comparison of Effect of Mixed Acid (70 Per Cent Sulfuric; 30 Per Cent Nitric) on "Chemi-Steel" and Cast Iron.

If the different kinds of commercial iron are arranged in the order corresponding to the ease with which they are attacked by dilute nitric acid (1 N), this order is the reverse of that for sulfuric acid; commercially pure iron dissolves relatively fast, less pure, such as gray and white cast iron and malleable iron, dissolve slowly, and steel lies between the two classes.[4]

Iron Alloys.—The alloying of iron with other elements, such as for example chromium and silicon, markedly changes its behavior towards nitric acid.

"Chemi-Steel," an acid-resisting steel of unstated constitution (see p. 33), is more resistant to acids than is the best quality gray cast iron. It is not suitable for use with nitric acid as dilute as 25 per cent, but with concentrated nitric and mixed nitric and sulfuric acids it appears somewhat superior to cast iron in its resistance to solution and greatly superior in its resistance to pitting and cracking.

While the addition of chromium to iron is said to lessen its resistance to sulfuric and hydrochloric acids, it in general increases it to nitric acid, but there are five classes of alloys, with reference to this property, depending on the amount of chromium present.[5]

Class	Per Cent Cr	Behavior Towards Nitric Acid
1.	Less than 4%	More easily soluble in dilute, less in concentrate
2.	4–14%	Resistance to dilute acid increases greatly
3.	14–20%	Resistance increases nearly proportionally to Cr
4.	20–40%	Like Cr alone, though alloys dissolve in cold dilute acid containing 5% NaCl
5.	40–100%	Very resistant; resist boiling dilute acid even containing NaCl

The alloys not attacked by dilute nitric acid are very resistant to corrosion, and that containing 40 per cent Cr showed no change after two years' exposure in the laboratory. To be transported safely in steel or iron drums concentrated nitric acid must contain a little sulfuric acid, as mentioned above, but if the iron of the container is alloyed with 5 per cent chromium, the addition of sulfuric acid is unnecessary.

These tests were made on alloys free from carbon, which were found to be less hard and with better mechanical properties than when carbon was present.

Duraloy is the trade name of a chromium-iron alloy that has recently been developed commercially and put on the market. It is said to be very resistant to corrosion and oxidation.[5a]

A chromium alloy has been patented which consists of iron containing 10 per cent chromium, 2 per cent molybdenum and no carbon.

The high melting, acid resisting steel of the Crucible Steel Company of America (see p. 34) shows the following behavior towards nitric acid as compared with other metals and alloys; the time data can unfortunately not be given.[5a]

ACTION OF 32 PER CENT NITRIC ACID

LOSS IN WEIGHT IN GRAMS PER SQUARE METER

Crucible steel, grade 4–2	0.64
" " " 3–2	0.77
High Cr, Ni steel	0.42
" Cr, Si "	0.77
25 per cent Ni	2608
Wrought iron	2658
Copper steel	3291
Monel metal	3340
High Cr steel	0.15

The ferro-silicon alloys, discussed more fully under sulfuric acid, are also very resistant to nitric acid. The extent of the action of two different concentrations is shown in the following table:[6]

Strength of Acid	Duration of Test	Temperature	Loss in Grams per m² per Hour
71% HNO_3	One year	Room	0.0058
10% “ (approx.)	Five weeks	80-85°	0.0595

The alloy tested contained between 14 and 15 per cent silicon. The depth of corrosion of the same material by nitric acid is shown in the following table in terms of centimeters per year.

Strength of Acid	Depth of Corrosion
70% HNO_3	0.000477 cm. per year
25% “	0.0000523
10% “	No loss

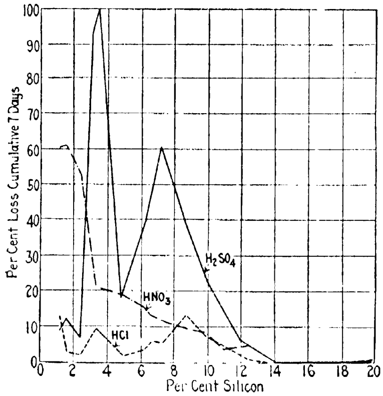


FIG. 9.—Variation of Corrosion of Duriron with Changes in Per Cent Silicon.

The relative action of different chemicals on a similar product of different manufacture is shown in the following table:[7]

Loss of Weight of Sample in	1st 24 Hrs.	2nd 24 Hrs.	3rd 24 Hrs.
HNO_3, 1.4 s. g.	0.10	0.02	0.02
“ 1.1 “	0.70	Nil	Nil
Acetic acid, 60%	0.03	0.01	“
Chromic “ 10%	0.07	Nil	“
Tartaric “ 25%	0.05	0.03	0.03
Iodine, satd. soln.	Nil	Nil	Nil
Bromine water, satd. soln.	0.01	0.01	“
$CaOCl_2$ satd. soln.	0.04	0.01	0.01
$CuSO_4$, acid	Nil	Nil	Nil
“ alkaline	“	“	“
$FeSO_4$, solution	0.06	“	“
$ZnCl_2$, 30% solution	0.03	“	“
NH_4Cl, solution	0.05	0.02	0.01
Fused sulfur	0.06	0.01	Nil
“ NH_4NO_3	Nil	Nil	Nil

Other Metals.—The action of quite dilute nitric acid (0.2 normal, or about 1¼ per cent) on eight metals has been studied under various conditions, the details of which together with the analyses of the metals used are described under sulfuric acid, pp. 48 and 49. The extent of the action is shown in the following table:[8]

THE ACTION OF 0.2 N HNO_3 ON METALS AT 17-20°

LOSS IN GRAMS PER SQUARE METER PER HOUR

Metal	7 Days, ½ l. Acid Renewed Daily	4 Hours, 1 l. Acid Not Changed	28 Days, ½ l. Acid Not Changed
Zinc	* 10.1	95.0	0.394
Cast Iron	* 9.2	65.0	0.372
Wrought Iron	* 8.6	32.5	0.298
Aluminum	0.060	0.5	0.080
Lead	* 5.83	9.0	0.937
Copper	0.148	0.5	0.079
Tin	2.38	40.5	1.01
Nickel	2.50	1.0	0.312

* Estimated on the basis of action lasting less than 7 days.

Non-ferrous Alloys.—An alloy of 40 parts cobalt and 60 parts tin was found to be very brittle[9] but extremely resistant to acids. If, however, 5-20 parts of this mixture are alloyed with 95-80 parts of copper, an alloy is obtained which, it is said, may be machined, and still retains its acid-resisting qualities, especially towards dilute nitric acid. The inventor calculates that it would take more than five years for dilute acids to dissolve a layer 1 mm. thick.

Monel Metal.—Monel metal is not resistant to nitric acid.[9a]

Nichrome, a nickel-chromium alloy (p. 50), is acted on by nitric acid at the rates shown in the following table:[10]

ACTION OF NITRIC ACID ON NICHROME

Strength of Acid	Temp.	Loss in $g/m^2/hr$ During the Periods			
		0–48 Hr.	48–72 Hr.	72–142 Hr.	0–142 Hr.
Concentrated (70%)	25°	1.938	2.100	1.591	1.795
Dilute, 4 M. (about 25%)	"	1.793	1.517	1.014	1.363
		Loss in $g/m^2/hr$ in 4 Hours			
Concentrated (70%)	95–98°	178.0			
Dilute, 4 M. (about 25%)	"	160.7			

During the war baskets of nichrome wire gauze were successfully used for straining suspended picric acid from the spent acid resulting from the nitrating operation. A typical spent acid from this source contained 45 per cent sulfuric acid, 3 per cent nitric acid and 0.5 per cent picric acid.

In this same spent acid specially pure cast aluminum dippers (containing as little copper as would permit successful casting) stood up well, being used for months without appreciable deterioration.

Tests carried out on stellite at Purdue University (see p. 52) showed that 20 per cent nitric acid even at the boiling temperature had extremely little effect on the alloy. There was slight tarnishing at the edges of the sample, but the loss in weight was reported as negligible.[10, 5]

Hydrochloric Acid.

Hydrochloric acid, the last of the trio of commercially most important acids, is chemically the most active of the three *as an acid* (as distinguished from activity in oxidation, reduction or the like), contrary to the popular conception. Sulfuric acid, because of its comparative non-volatility, expels hydrochloric acid when heated with chlorides, and nitric acid, because it is a strong oxidizing agent, attacks substances unattacked by hydrochloric acid alone (e. g., copper); but in purely acid reactions, that is, those involving the hydrogen ion, hydrochloric acid is the most active.

Since hydrochloric acid is not an oxidizing agent, it does not attack those metals which follow hydrogen in the electromotive series, As, Cu, Sb, Bi, Hg, Ag, Pd, Pt, Au (p. 46), provided no oxidizing agent is present. The other metals it attacks more or less violently. Among oxidizing agents are hydrogen peroxide, air, oxygen, nitric acid (forming aqua regia), chlorates, etc. It follows that it is very important to know whether the possible exposure of some metal, say copper, to hydrochloric acid is to be in the presence or absence of air or any other possible oxidizing substance. A mixture of HCl (s. g. 1.125) and H_2O_2 (30 per cent) dissolves not only copper, bismuth, nickel and antimony, but gold and platinum which are unaffected by the acid alone; this mixture does not affect silver nor mercury, and attacks lead very slightly owing to the formation of an insoluble protective coating. When air is excluded hydrochloric acid attacks copper practically not at all, but in the presence of air the corrosion is very rapid:[1]

$$2Cu + 4HCl + O_2 \longrightarrow 2CuCl_2 + 2H_2O.$$

Hydrochloric acid attacks the more electropositive metals (among them are aluminum, zinc, iron, nickel, tin and lead) rapidly under most conditions, but the purity of the metal and the concentration of the acid have, of course, a great effect. Perfectly pure zinc, for example, is not attacked by acid of concentrations less than 0.5-1.0 N.[12] The presence of arsenic, lead or cadmium in the zinc is said not to increase the rate of its solution, but very small amounts of nickel, platinum or gold, of the order of 0.01 per cent, increase the rate appreciably.

Ferro-silicon alloys are not resistant to hydrochloric acid. Fig. 10 shows the results of tests made by the Duriron Company.

Perfectly dry hydrogen chloride gas has practically no action on metals. In hydrochloric acid plants, for example, cast iron pipes may be used for conveying the hot gases from open roasters, and they stand up well as long as the gases are hot (above 120°), but they are rapidly attacked by cool gases owing to partial condensation of liquid hydrochloric acid at lower temperatures.[13]

Iron.—The following is an interesting instance of what is fundamentally hydrochloric acid corrosion of iron. Acid corrosion of stills and condensers has given oil companies much trouble, both the pipe and the shell types being equally attacked. It has been determined that the cause of the corrosion is the salt water contained in the oil. The salt water is held very tenaciously in the oil in an emulsified condition. Field storage to remove salt water and other impurities is regular practice, nevertheless the field-refinery-piped oil averages 0.5-1.5 per cent British Standard Water, of which 60-75 per cent is salt water.

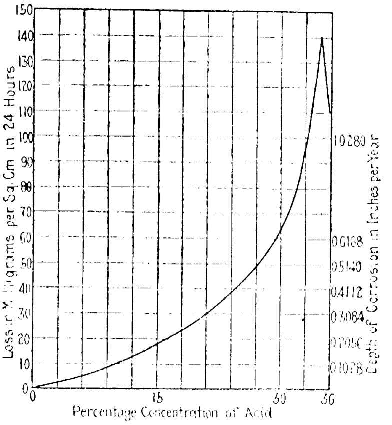


FIG. 10.—Effect of Hydrochloric Acid at Different Concentrations on Duriron.

At the refinery a mixture of oil and vapor goes to the necessary apparatus which allows the vapor to separate from the residual oil and pass through a series of dephlegmators and condensers. The lighter vapor passes from the top of the last dephlegmator to the condenser. From there the gasoline flows to the receiving house. Lines from other dephlegmators run through coolers into the receiving house where the necessary cuts are made.

Tests were run to determine the cause of corrosion. Eight stills, steam-bottom fitted, were equipped with dephlegmators, condensers, and coolers. Linked together, the stills were of continuous-run type, each having a higher temperature than the previous one. Intermittent operation was adopted. A leak was noticed at the end of a period of 2½ years, and the tubes were found, on examination, to be corroded for a length of 18 inches on the oil side.

Although dissolved gases such as hydrogen sulfide, oxygen, and carbon dioxide can cause corrosion, conditions indicated chlorides to be the factor sought. The oil brine analyzed 2.2 per cent $MgCl_2$ and 6.5 per cent NaCl. Theoretically the brine should partially settle in the first still and the remainder dehydrate in the next so that the salts should pass the remaining stills without trouble. Actually it was proved that in passage through the dephlegmators an acidity equal to 8.23 grains of HCl per gallon of water is acquired. Where petroleum contains 1 per cent brine, HCl will be formed in the ratio of 3.39 lbs. to 1000 barrels.

$MgCl_2$ was thought to be the source of the acid since it volatilizes at a red heat and hydrolyzes in the presence of water, forming HCl and magnesium oxychlorides,[13a] and it was thought that the hydrolysis of $MgCl_2$ contained in the brine formed HCl, the vapors of which caused rapid corrosion wherever they condensed. Laboratory experiments were then run which showed that the water of crystallization from crystallized $MgCl_2$ is sufficient to start the hydrolysis and that $MgCl_2.6H_2O$ and water-free oil produced HCl vapors between 172-200° C., thus indicating that the hotter stills are the more favorable for corrosion, with No. 4 very favorable. Actually corrosion took place in the last two dephlegmators and the condensers used with the last dephlegmator. The most severe corrosion was found where cooling was below 100° C. That corrosion seems only to take place in condensers where stills hold a temperature average of 175-250° C. is confirmed by Friend.[13b] Steam assists the hydrolysis and the resulting dilution naturally accelerates the corrosion. After 1½ years corrosion took place in a baffle-plate heat exchanger in which the oil made four passes through tubes to pass from bottom to top exit. Since abrasive matter is heavier than oil and the hole was on the inside at the top, acid corrosion is proved although the oil temperature did not exceed 110° C.

It has been suggested that the acid formed be neutralized by ammonia. For this purpose aqueous ammonia was found best. Ammonia was supplied by a ¼-in. line to the vapor line just before it leaves the stills and before reaching the first dephlegmators. The reaction must be alkaline to prevent acid vapor corrosion and the action of NH_4Cl on metal. This plan was successful (a heavy deposit of NH_4Cl being recovered later) although a certain amount of corrosion still took place due to the formation of iron salts.

Continued experience has shown ammonia introduced in the fractionating system of pipe stills to be the best combative agent thus far found to reduce the corrosive effect of HCl. It also no doubt neutralizes organic acids which might aid in the corrosion. Ammonia will not prevent such effects as noted in the heat exchanger, however, since it is introduced beyond that point in the vapor system. Also the use of ammonia on a bench of stills would be rather difficult, owing to the necessity for introduction into the vapor system of each still. Thus, on the whole, the most practical solution in all such cases is to remove the salt water from the crude oil as it comes from the well, or at least before it is put into the pipe line. Various methods of dehydration of crude oil have been proposed and some are in use, but none has yet removed the brine so thoroughly that this sort of corrosion is entirely prevented.

A more detailed account of these experiments is given by Foster and Roberts.[13c]

The action of hydrochloric acid on the new acid resisting steel of the Crucible Steel Company of America is shown in the following table compared with the action on other metals and alloys; unfortunately neither time nor temperature data are available [5a] (see p. 34).

ACTION OF 32 PER CENT HYDROCHLORIC ACID

LOSS IN WEIGHT IN GRAMS PER SQUARE METER

Crucible steel, grade 4-2	51.6
" " " 3-2	63.5
High Cr, Ni steel	717
" Cr, Si "	...
25 per cent Ni	34.6
Wrought iron	405
Copper steel	312
Monel metal	20.3
High Cr steel	678

Zinc.—The rate of solution of zinc in hydrochloric acid is not constant, but increases to a maximum;[14] the rate is greater per unit apparent surface with rough zinc than with smooth, and greater with hydrochloric than with sulfuric acid, the solutions compared being isohydric (i. e., having the same hydrogen ion concentration or acidity). The rate of solution increases more rapidly than the hydrogen ion concentration, and is greater with zinc that has previously been treated with an iodine solution than with untreated metal. The black deposit that forms during the reaction on the zinc accelerates the rate of solution, as does also agitation of the solution and changing the acid. If a piece of zinc which has reached its maximum rate of solution in 2 N HCl is placed in fresh acid, the reaction velocity increases.

These phenomena are explained by the hypothesis that ordinary zinc is in a passive condition due to a double layer of oppositely charged molecules on its surface, and that any factors that disturb these effect the solution velocity.[15] This hypothesis is also applicable to other metals.

Various Metals.—The action of 0.2 N HCl was included in the series of experiments described in part on pages 29 and 48, where the analyses of the metals used and the experimental conditions are given. The figures for hydrochloric acid follow:

ACTION OF 0.2 N HCl ON METALS AT 17–20°

LOSS IN GRAMS PER SQUARE METER PER HOUR

Metal	7 Days, ½ l. Acid Renewed Daily	4 Hours, 1 l. Acid Not Changed	28 Days, ½ l. Acid Not Changed
Zinc..........	* 12·8	117.5	0.46
Cast iron......	* 10.8	75.0	0.43
Wrought iron..	* 11.3	4.2	0.49
Aluminum.....	0.20	0.25	0.25
Lead..........	0.71	1·5	0.10
Copper........	1.79	0.75	0.47
Tin...........	0.25	0.50	0.13
Nickel.........	0.15	0.25	0.06

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* Estimated on the basis of action lasting less than 7 days.

From the marked action on copper it is evident that the experiments were carried out in the presence of air.

Pure antimony resists hydrochloric acid cold and moderately hot, the basis of Hargreaves' and Robinson's British patent (5809 of 1882) for antimony cooling pipes, evaporating pans, etc.

Formaldehyde has an inhibiting effect on the solution of metals by mineral acids, and hydrochloric acid containing 1 per cent $HCHO$ can be used for pickling rusty steel without much effect on the steel itself.[16]

Electromotive Series of Metals.—W. D. Richardson [16a] has worked on the elucidation of some inconsistencies of the electromotive series, as to solution of metals in acids.

He reports experiments made on the rate of solution of four kinds of iron, rolled copper, and aluminum both with and without catalyzers of platinum, silver, copper, nickel, and formaldehyde, in sulfuric, hydrochloric, and nitric acids respectively.

The results of his experiments led him to the following conclusions:

(1) Inconsistent behaviour of the metals in corrosion and acid solution phenomena on the basis of the electrochemical series can only be explained by taking into consideration a number of factors.

(2) The principal factors are solution tension, the hydrogen influence, the oxygen influence, the carbon dioxide influence, the cathode influence and the halogen influence.

(3) Corrosion and solution of metals in acids may be considered as actions tending to go forward at rates proportional to solution tension and hydrogen ion concentration, but subject to the accelerating and retarding influence of many substances acting as catalyzers.

(4) Indications of the sensitiveness of various metals to the

hydrogen and oxygen influences can be obtained by their behavior when treated as couples in dilute acids and neutral salts and connected through a sensitive voltmeter or galvanometer.

(5) Studying the behavior of metallic catalyzers on the rates of solution of copper-bearing iron, pure open-hearth iron, gray cast iron and semi-steel in normal sulfuric, hydrochloric and nitric acids at 16° C. with several metallic catalyzers, it was found that the rolled metals in general showed a different and opposite behavior to that of the cast metals.

(6) Again, the behavior of any of these metals in the non-oxidizing acids, sulfuric and hydrochloric, is as a rule different from the behaviour in nitric.

(7) A similar rule holds for corrosion in these metals and also for their solution in the above acids without catalyzers.

(8) Although the mode of action of a soluble organic catalyst, such as formaldehyde, is probably different from that of the metallic catalysts, nevertheless, the opposite tendency in the case of different metals in oxidizing and non-oxidizing acids is revealed in this case also.

(9) The rates of solution of copper-bearing and pure open-hearth iron in nitric acid are catalyzed negatively by silver, copper and formaldehyde, but the rates of grey cast iron and semi-steel are catalyzed positively by the same three catalysts.

(10) No pronounced change of rate is shown by silver, copper or formaldehyde acting as catalysts on copper-bearing or pure open-hearth iron in sulfuric or hydrochloric acid.

(11) The same is true of silver and copper when acting on gray cast iron and semi-steel, but in contrast with this behavior formaldehyde catalyzes these metals strongly in a negative direction in the non-oxidizing acids.

(12) Platinum catalyzes the rates of copper-bearing and pure open-hearth iron positively in normal sulfuric and hydrochloric acids, and the action is more pronounced in the case of pure open-hearth iron than in the case of copper-bearing iron.

(13) On the contrary, the rates of these metals in normal nitric acid are catalyzed negatively by platinum.

(14) The rate for copper is not certainly catalyzed by any of the catalysts used.

(15) Nickel as a catalyst produces no effect on any of the metals in any of the acids except aluminum in hydrochloric acid.

(16) Aluminum is not affected by any of the catalysts in nitric or sulfuric acids.

(17) In normal hydrochloric acid the rate for aluminum is catalyzed strongly by nickel and still more strongly by platinum.

(18) A similar action might be expected in sulfuric acid and the lack of action in this case is probably due to the oxygen influence of sulfuric acid on aluminum.

(19) Under conditions of corrosion the cast metals are relatively less attacked in the presence of much oxygen than the

purer rolled metal. They are also relatively less attacked by an oxidizing acid, such as nitric, than by the non-oxidizing acids, sulfuric and hydrochloric. The catalysts, silver, copper and formaldehyde, all reverse this action and cause the rates of the cast metals in nitric acid to be increased and the rates of the copper-bearing and pure open-hearth irons to be reduced. Platinum, while catalyzing the rolled metals negatively in nitric acid, catalyzes them positively in sulfuric and hydrochloric acid, and is without action on the cast metals in any acid. The failure of the platinum to catalyze the cast metals is probably due to the evolution of poisons from impure metals by the action of the acid.

Alloys.—The action of hydrochloric acid on commercial ferro-silicon alloys is considerably greater than that of either sulfuric or nitric acids:[6]

Strength of Acid	Duration of Test	Temperature	Loss in Grams per m^2 per Hour
3-4%	5 weeks	80-85°	0.111

Data showing the depth of corrosion in terms of centimeters per year, based on a 120 days' test, are given in the following table:

Strength of Acid	Depth of Corrosion
25% HCl	0.0205 cm. per year
5% "	0.0082

On nichrome, however, the action of hydrochloric is less vigorous than that of nitric acid, and sometimes more and sometimes less than that of sulfuric acid. The following table shows the action of both concentrated and dilute acids, hot and cold.[10]

ACTION OF HYDROCHLORIC ACID ON NICHROME

		Loss in g/m^2/hr During the Periods			
Strength of Acid	Temp.	0-48 Hr.	48-72 Hr.	72-142 Hr.	0-142 Hr.
Concentrated (37%)	25°	0.357	0.226	0.213	0.264
Dilute, 4 M. (about 15%)	"	0.468	0.335	0.284	0.355
		Loss in g/m^2/hr in 4 Hours			
Concentrated (37%)	95-98°	319.1			
Dilute, 4 M. (about 15%)	"	114.4			

Stellite is reported fairly resistant to hydrochloric acid.[10.5]

Material Tested	Action
Cast festel stellite	Corroded, loss 0.1 per cent
Hammered festel stellite	Corroded, loss 0.29 per cent
Cast soft malleable stellite	Corroded, loss 0.21 per cent
Hammered soft malleable stellite	Slightly corroded, luster destroyed, loss 0.12 per cent
	whole destroyed, loss 0.05 per
All other grades (see p. 52)	Slightly corroded, luster on the cent

Monel metal is not resistant to hydrochloric acid.[9a]

The great reactivity of hydrochloric acid with metals makes it one of the most difficult acids to handle in industrial operations and non-metallic materials usually have to be used in plant operations. See Chapter VII.

Miscellaneous Acids, Organic and Inorganic.

Halogen Acids.—The halogen acids other than hydrochloric (hydrofluoric, -bromic and -iodic acids) are all detrimental to metals, though as much as 2 per cent hydrofluoric acid in sulfuric acid does not harm lead[17] and strong hydrofluoric can be transported in viou drums.[17a] Hydrobromic acid, and hydroiodic still more, is oxidized by the air to water and free halogen, a mixture having a corrosive action on almost all common metals.

Selenic Acid, H_2SeO_4, though scarcely coming into consideration commercially, is interesting as being the only single acid that will dissolve gold (aqua regia being a mixture of hydrochloric and nitric acids).

Acetic Acid, CH_3CO_2H, of the organic acids is by far the most important commercially, and one of the strongest. It is used extensively in organic syntheses as are its derivatives, acetic anhydride and acetyl chloride. Copper and aluminum are both little acted on by strong acetic acid, but aluminum is attacked more strongly than copper by the dilute acid. The addition of H_2O_2 to acetic acid produces a mixture which dissolves copper, silver, mercury, lead and bismuth, but the presence of H_2O_2 does not affect the action on aluminum.[11]

In view of this it is not surprising that the presence or absence of air has little effect on the corrosion of aluminum; the acid concentration is the all-important factor. The rate of solution falls as the concentration rises to 99 per cent and above, but the removal of the last 0.05 per cent water raises the rate a hundredfold. Absolute acetic acid produces a crystalline acetate different in form from that produced by aqueous solutions.[18] In the following table are given data on the action of boiling acetic acid of different strengths on aluminum which had been annealed and washed with sodium hydroxide solution and nitric acid before exposure to acetic acid. The analysis of the aluminum was:

	Per Cent	
Si	0.45	
Fe	0.45	
Cu	0.00	
Al	99.1	(by difference)

SOLUTION OF ALUMINUM IN BOILING ACETIC ACID

RATES OF LOSS IN GRAMS PER SQUARE METER PER HOUR

Strength of Acid	Initial Rate	Final Rate *	Grams Al Diss. Which Produce Turbidity in 100 c. c.
99.9%	....	0.029	....
98	....	0.146	....
90	....	0.688	....
80	....	1.229	....
70	....	1.375	....
60	1.625	1.708	0.11
50	....	1.750	....
40	1.833	2.050	0.157
20	1.875	2.220	0·19
10	1.125	2.425	0.24
1	0.058	5.000	0.058
0.2	0.250	3.208	....

---

* The final rate is the rate after saturation of the acid solution is reached; see column 4.

The action of cold acetic acid on aluminum is shown in the following table:

SOLUTION OF ALUMINUM IN ACETIC ACID AT 20°

RATES OF LOSS IN GRAMS PER SQUARE METER PER HOUR

Strength of Acid Per Cent	Rate of Solution
99.2	0.0000
98	0.00004
95	0.0006
90	0.0011
85	0.0024
80	0.0024
75	0.0025
70	0.0025
65	0.0026
60	0.0025
55	0.0025
50	0.0023
25	0.0027
15	0.0035
10	0.0038
5	0.0033
2.5	0.0035
1	0·0046
0.5	0.0058
0.25	0.0071
0.1	0.0117—0.0092
0.02	0.0133
0.004	0.0042
0.000 (distilled water)	0.0000

Commercially Pure Iron.—"Commercially pure iron" is finding increased use in industries in places where corrosion conditions are unusually severe because of its resistance to mildly acid and strongly alkaline solutions. Such iron contains usually less than 0.1 per cent carbon, sulfur, manganese and copper,[18a] and its resistance to corrosion is largely due to the fact that its great homogeneity results in the absence of areas of difference of potential on its surface when immersed in electrolytes, and consequently in an absence of electrolytic action. It is well known that many old and even ancient samples of iron were of high purity, and that they have shown a high degree of freedom from rust.

The tabulated results of a test in which commercially pure iron and a sample of steel were tested in acetic acid show the superiority of the iron in this respect. The samples were kept in 3 per cent acetic acid at approximately 38° C. for 45 days.

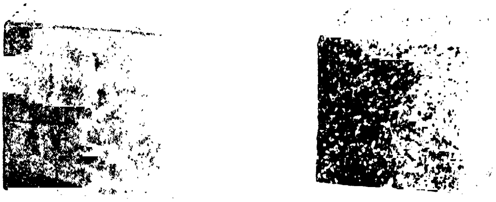
ANALYSIS OF SAMPLES

Per Cents	S	P	C	Mn	Cu
Commercially pure iron	0.015	0.006	0.010	0.012	0.018
Steel	0.048	0.077	0.140	0.288	0.372

ACTION OF 3 PER CENT ACETIC AT APPROXIMATELY 38° C. FOR 45 DAYS

	Total Loss, g/m^2	Average Loss, $g/m^2/hour$
Commercially pure iron	592	0.548
Steel	1160	1.074

A product marketed under the name "Chemi-Steel" is claimed to be far superior to the best gray cast iron in its resistance to acetic acid; with glacial acetic acid at low temperatures there is not a great deal of difference, but at 70° the cast iron is attacked and dissolved twice as fast; with 10 per cent acetic acid the difference is even more marked, the cast iron being dissolved four times as fast as Chemi-Steel at 30° and 100 times as fast at 70° It is claimed by the makers that this difference puts their product in a position to be used with 10 per cent acetic acid with practically no loss, while cast iron is unfitted for this service.



Chemi-Steel Cast Iron

Courtesy The M. W. Kellogg Company

FIG. 11.—Comparison of Effect of 10 Per Cent Acetic Acid at 70° C. on "Chemi-Steel" and Cast Iron.

In comparison with other metals and alloys the recent high melting, acid resistant steel of the Crucible Steel Company of America shows the following behaviour towards glacial acetic acid; no time or temperature conditions are reported[5b] (see p. 34).

ACTION OF GLACIAL ACETIC ACID

LOSS IN WEIGHT IN GRAMS PER SQUARE METER

Crucible steel, grade 4-2	9.5
" " " 3-2	0.51
High Cr, Ni steel	12.3
" Cr, Si "	0.00
25 per cent Ni	12.1
Wrought iron	29.9
Copper steel	18.9
Monel metal	1.08
High Cr steel	1.04

Neither fresh nor stale butter attacks the steel, and lactic acid only discolors it slightly; it is somewhat attacked by saturated oxalic acid solutions, and is not very resistant to sulfurous acid.

On commercial ferro-silicon neither 9.9 per cent nor glacial acetic acid has any appreciable effect;[6] tests were carried out with the former for one year at room temperature and with the latter for two weeks at 90° without weighable loss of metal. The glacial acid had a strength of 99 per cent.

Monel metal showed the following losses in weight when exposed in sheet form to boiling acetic acid for eight hours:

SOLUTION OF MONEL METAL SHEET IN BOILING ACETIC ACID

RATES OF LOSS IN GRAMS PER SQUARE METER PER HOUR

Strength of Acid	Loss
10 per cent	0.11
26 " "	0.12
56 " "	1.70
90 " "	1.85

The same material lost 0.005 g. per square meter per hour during eight months' exposure to cold glacial acetic acid.[9a] Monel metal is excellent in its resistance to fatty and many other organic acids, urine, dyeing solutions and beverages, and resists fairly well weak phosphoric, hydrocyanic, hydrofluoric and citric acids. It is not resistant to sulfurous and chromic acids.

At room temperature nichrome is attacked by both dilute (4M, 24 per cent) and concentrated (97 per cent) acetic acid more strongly than aluminum is, but at higher temperatures, while the concentrated acid attacks nichrome more strongly than aluminum, the action of the dilute acid is less on nichrome than on aluminum.[10] The quantitative results follow.

ACTION OF ACETIC ACID ON NICHROME

		Loss in g/m²/hr During the Periods			
Strength of Acid	Temp.	0-48 Hr.	48-72 Hr.	72-142 Hr.	0-142 Hr.
Concentrated (97%).	25°	1.790	2.00	2.305	2.079
Dilute, 4 M. (24%).	"	0.114	0.126	0.106	0.112

ACTION OF ACIDS ON STELLITE

Material Tested	Aqua Regia	Hydrofluoric Acid 38 Per Cent	Phosphoric Acid 90 Per Cent	Acetic Acid 10 Per Cent	Oxalic Acid 5 Per Cent	Carbolic Acid 5 Per Cent
Cast festel stellite	Dissolved	Corroded, loss 1.98 per cent	Tarnished slightly at edges	No change	Corroded, loss 0.12 per cent	No change
Hammered festel stellite	Dissolved	Corroded in spots, loss 1 per cent	Tarnished slightly at edges	Very slightly tarnished, loss 0.02 per cent	Corroded, loss 0.01 per cent	No change
Cast soft malleable stellite	Dissolved	Not attacked	No change	No change	Corroded in spots, loss 0.019 per cent	No change
Hammered soft malleable stellite	Dissolved	Film of tarnish, loss negligible	No change	No change	No change	No change
Cast hard malleable stellite	No change	Tarnished considerably, luster destroyed	No change	No change	No change	No change
Hammered hard malleable stellite	No change except in spots	No change	No change	No change	No change	No change
No. 2 stellite	No change except in spots	Tarnished	No change	No change	No change	No change
No. 3 stellite	Tarnished very slightly	Tarnished in spots	No change	No change	No change	No change
No. 4 stellite	Tarnished	Tarnished slightly	No change	No change	No change	No change

	Loss in g/m²/hr in 4 Hours
Concentrated (97%) . 95-98°	1.60
Dilute, 4 M. (24%) . "	0.69

The action of several miscellaneous acids on stellite (see p. 52) is shown in the table on page 71.[10a]

Cast hard malleable stellite best of all resisted the action of aqua regia. While the action of oxalic acid was intensified by boiling, heating did not visibly increase the action of phosphoric or carbolic acid; the action of acetic acid on the first two samples in the table was slightly increased by boiling, but no increased action was observed on the other samples.

Other Organic Acids.

Boiling *butyric acid* of 99 per cent strength has practically no effect on aluminum, but above this strength it shows a sudden rise in the rate of its action on the metal like acetic acid. *Propionic acid* behaves in the same way. Boiling 77 per cent *formic acid* attacks aluminum very rapidly. Mixtures of *palmitic, stearic* and *oleic acids* do not attack the metal below 270° but invariably attack it above 300°.[18]

The action of certain organic acids on tin is of especial interest because of the extensive use of tin-lined containers for canned foods. In the absence of air tin is not oxidized by 5 per cent *tartaric acid*, but in the presence of air oxidation of the metal takes place at the surface of the solution, oxides of tin and stannous tartrate being formed. With a restricted amount of oxygen the SnO first formed is gradually oxidized further and forms a brown colloidal solution which on heating is changed to a bluish white hydrosol containing hydrated SnO_2 and possibly an intermediate oxide.[19]

Tenth normal and hundredth normal solutions of *oxalic, tartaric, citric, malic, acetic* and *lactic acids* attack the tin coating of cans rapidly in the air but scarcely at all *in vacuo* or in an atmosphere of carbon dioxide. Most neutral salts have but little effect, but nitrates catalyze the reaction positively. All the acids oxidize more than their equivalent of tin, the main product being $Sn(OH)_2$, insoluble in all the acids except tartaric and oxalic.

With zinc the results are similar, except that oxalic acid has scarcely any effect on the metal and indeed tends to inhibit the action of the other acids.[20]

That duralumin may be used for cooking vessels is indicated by experiments with cooking-salt solutions and dilute acetic acid; neither showed traces of copper after being boiled or allowed to stand four days in duralumin vessels. Foods showed no greater action than tap water.[21] Duralumin can be hot or cold rolled, forged or drawn. Its melting point is 650°, its specific gravity less than 2.8, and its composition:[22]

Al	94.6%
Cu	3.9
Fe	0.45
Mg	0.75
Mn	Trace
Si	0.21
Zn	None

The action of a number of organic acids on commercial ferrosilicon is shown in the following table:[6]

Acid	Duration of Test	Temp.	Loss, g/m²/hr
Benzoic, fused	16 hours	125-135° C.	0.065
Butyric, 98%	One month	Room	0.0054
Formic, 85%	One week	"	0.0000
Hydrocyanic, 98%	" "	"	0.0031
Lactic, 99%	One month	"	0.0003
Oxalic, 30%	48 hours	85-90°	0.3031

The action of some other organic acids on the same material in terms of depth of corrosion in centimeters per year is shown in the next table.

Acid	Depth of Corrosion
99% acetic acid	0.0000477 cm. per year
7.9% oxalic acid (hydrated)	105
Commercial oleic acid	0218
31% pyrogallic acid	0523

Picric Acid.—Because of its importance as a military explosive and because of the dangerous character of some of its salts, the action of picric acid, $C_6H_2(NO_2)_3OH$, on metals is of interest and importance. The following results were obtained by heating 2 g. picric acid at 125° (the acid was therefore molten) in a tube, in a thermostat, with 1 g. metal filings or shavings for 8-9 hours. The mass was dissolved in hot water, filtered, and evaporated to dryness, the residue treated with nitric acid to destroy picrates, and the solution analyzed for the metal in question.[23]

WEIGHT OF METAL DISSOLVED BY 2g MELTED PICRIC ACID FROM 1g FILINGS AT 125°

Metal	Wt. in Grams
Sn	0.0000
Al	0.0488
Fe	0.1530
Cu	0.1754
Ni	0.1862
Zn	0.2046
Pb	0.2798

In solution picric acid and trinitrocresol $C_6H.CH_3.(NO_2)_3OH$, react with metals as shown in the following table. In this case plates of iron, zinc, copper and brass 50 x 100 x 0.5 mm. were used and also plates of lead and aluminum 50 x 100 x 4 mm.; these were let stand for four weeks in 200 g. water containing 50 g. respectively of picric acid or trinitrocresol.[23a]

ACTION OF PICRIC ACID AND TRINITROCRESOL IN SOLUTION ON METALS AT ROOM TEMPERATURE

Metal	Picric Acid		Trinitrocresol	
Lead	Immediate action, strong corrosion; salt res. in soln.	3.91 g	Same as picric acid	4.15 g
Iron	As above	13.71	As above	3.78
Zinc	" "	18.86	Slight corrosion, residue	0.48
Copper	Res. in soln.	2.37		1.04
Brass	" " "	1.19		1.02
Aluminum	Brown crusts containing some picrate	3.94	Brown crusts containing some trinitrocresylate	2.97

Corrosion.

While corrosion in its broader sense means a slow destruction or wearing away, usually of a metal by chemical reagents, and in this sense would include all the cases considered above, in its more restricted sense it usually refers to reactions like the rusting of iron, actions that are, compared with those above, extremely slow and are caused by fairly dilute solutions. For the sake of convenience the cases considered here under this head will be those not easily classified under previous headings, such as the action of acidic salt solutions (solutions that are acid owing to the hydrolysis of the salt of a weak base and a strong acid), the action of dissolved oxygen, of dissolved carbonic acid, and so forth.

The question of corrosion is one of great importance commercially, especially in marine engineering, and it has consequently been studied in great detail, but because of the great variety of conditions under which corrosion occurs and the somewhat complex nature of the factors which affect it, it cannot be said even now to be completely understood. So much work has been published on this subject that only a few of the more important available data can be given here.

The rusting of iron requires the presence of water and oxygen to reach a practicably appreciable velocity, and its velocity is much increased by the presence of carbon dioxide, but it seems pretty well established that the latter is not necessary for action to occur;[24] indeed an infinitesimal amount of rusting occurs in the absence of oxygen, but the rapidity of the corrosion is in general a linear function of the partial pressure of the oxygen in contact with the water that causes the rusting. These facts seem best explained by the hypothesis that the hydrogen ion is the fundamental cause of rusting, and that the first reaction is

$$\mathrm{Fe} + 2\mathrm{H}^{\cdot} \longrightarrow \mathrm{Fe}^{\cdot\cdot} + \mathrm{H}_2.$$

The concentration of hydrogen ion in pure water is only 10^{-7} grams per liter, so that this reaction is extremely slow; in addition to this the hydrogen separating on the surface of the iron soon brings the action to a standstill. If, however, dissolved oxygen is present, it acts as a depolarizer, permitting the reaction to continue. Finally, if carbon dioxide is present dissolved in the water, it increases the hydrogen ion concentration by the formation of weakly but appreciably ionized carbonic acid which increases the rate of rusting. Conversely alkalies hinder rusting by repressing the hydrogen ion concentration.

In a case where severe corrosion of wrought iron condenser tubes was found caused by a high CO_2 concentration in the water, the corrosion was stopped by the use on the water of a lime-soda softener.[25]

Electrical effects may hasten or hinder the corrosion. Tin, which is less electropositive than iron, when in contact with the latter metal increases the rate of its corrosion (e. g. the rapid rusting of damaged tin plate), while the more electropositive zinc in contact with iron protects the latter by itself dissolving and assuming the positive charges of the hydrogen ions. Examination shows that iron prone to rust has a greater number of areas of marked electropotential difference than has more resistant iron.

In the rusting of iron secondary reactions follow the initial reaction with the result that after long exposure the final product is ferric oxide, Fe_2O_3. The stages of the change are not quite certain, but probably a ferrous carbonate, $Fe(OH)(HCO_3)$ or $Fe(HCO_3)_2$, is first formed, which is oxidized to either $Fe(OH)_2(HCO_3)$ or $Fe(OH)(HCO_3)_2$ or both; these are hydrolyzed by water to $Fe(OH)_3$ which gradually passes to Fe_2O_3.[18, 19]

To sum up, an appreciable concentration of hydrogen ion is necessary for rusting; whatever increases this—acids or acidic salts—favors rusting, and whatever reduces this—alkalies or alkaline substances—inhibits rusting. Oxygen aids rusting by acting as a depolarizer. Other metals in contact with iron promote or inhibit the corrosion of iron according as they are less or more electropositive than iron.

There are many conflicting data on the relative resistance to corrosion of iron and steel, but it is generally considered that in sea water wrought iron stands up better than steel. Manganese is not believed to be a serious cause of rusting.[28]

A somewhat comprehensive series of experiments on the comparative corrosion of different kinds of iron and steel and of aluminum and copper in water and brine has recently been published.[43] The sheets tested were 6 inches square; the rolled sheets were number 16 gage, and the cast pieces were 1/8 inch thick. These pieces were exposed for 1000 days at room temperature to: 1. Distilled water at rest; 2. The same, plates dried semi-weekly; 3. Distilled water with air agitation; 4. The same, plates dried semi-weekly; 5. Ten per cent salt brine at rest; 6. The same, plates dried semi-weekly; 7. Ten per cent salt brine with air agitation; 8. The same, plates dried semi-weekly. The experiments were run in triplicate with good agreement.

The analysis of the samples was as follows:

Mark	Si	P	S	Mn	Carbon Total	Carbon Graphitic	Carbon Combined	Cu
AA.......	0.04	0.007	0.015	0.063	0.059	....	0·059	0.12
CC	0.03	0.005	0.016	0.16	0.056	....	0.056	0.10
BB	0.04	0.008	0.015	0.024	0.030	....	0·030	0.015
II.........	0.002	Trace	0.019	0.002	0.020	....	0.020	0·023
JJ	0.007	0.002	0.016	0.023	0.020	....	0.020	0.025
KK	0.008	0.002	0.013	0.020	0·030	....	0.030	0.000
UU	0.008	0.015	0.043	0.433	0.164	....	0.164	0.021
WW......	0.004	0.020	0.041	0.282	0.097	....	0·097	0.030
TT	0.005	0.075	0.290	0.450	0.119	....	0.119	0.080
VV	0.008	0.025	0.033	0.407	0·132	....	0.132	0.020
DD	0.14	0.12	0.014	0.31	0.023	....	0.023	0.000
EE	0.15	0 17	0.019	0.030	0.030	....	0·030	Trace
XX	0.003	0.052	0.013	0.029	0.060	....	0.060	0.047
FF........	2.71	0.82	0.120	0.32	3·21	2.62	0.59	0.000
SS........	2.24	0.40	0.122	0.44	3.08	2.67	0.41	0.000
LL	0.81	0.137	0.054	0.251	1·35	0.05	1.30	0.000
OO	0.48	0.143	0.044	0.216	1.55	0.05	1.50	0.000
MM	0.90	0.134	0.09	0.25	0.57	0.50	0.07	0.000
NN	0.77	0.164	0.067	0.26	2·44	1.44	1.00	0.000
GG	2.95	0.92	0.110	0.33	3.06	2.72	0.34	0.000
RR	2.15	0.327	0.121	0.46	3.15	2.35	0.80	0.000
PP	0.26	0.011	0.024	0.58	0.20	....	0·20	0.000
QQ	0.23	0.036	0.041	0.58	0.21	....	0.21	0.000

Key to the Marks: AA, CC, copper bearing; BB, II, open-hearth pure iron; JJ, KK, open-hearth cold rolled; UU, WW, open-hearth iron; TT, VV, Bessemer iron; DD, EE, genuine puddled iron; XX, charcoal iron; FF, SS, gray cast iron; LL, OO, white cast iron; MM, NN, malleable iron; GG, RR, semi-steel; PP, QQ, cast steel.

All of the plates experimented on were used in their original condition with their surfaces untreated in order to duplicate as closely as possible conditions met in industrial practice.

The plates were subjected to corrosion under the above outlined conditions and for final weighing were freed from rust by brushing and carefully controlled sand blasting. The losses due to corrosion are given in the following table:

CORROSION LOSS IN GRAMS AFTER 1000 DAYS AT ROOM TEMPERATURE

Mark	1	2	3	4	5	6	7	8
AA	22·7	18.0	177.5	110.4	45.9	131.1	a	a
CC	23.0	19.0	184.9	111.2	36.8	153.9	204.2	a
BB	28.4	21.5	160.8	111.6	51.2	145.7	164.8	a
II	26.6	27.9	155·4	89.7	48.5	133.5	148.7	247.9
JJ	24.1	16.4	223.1	128.5	41.3	107.2	124.3	253.0
KK	24.1	14.1	192.0	114.4	41.5	129.2	132.7	a
UU	21.3	12.2	188.6	95.9	51.1	176.8	146·5	a
WW	23.8	15.9	215.5	102.3	49.9	147.3	186.6	221.9
TT	29.5	14.1	178·4	96.8	53.5	161.8	171.0	252.1

Mark	1	2	3	4	5	6	7	8
VV	23.2	16.9	230.7	101.6	50.3	153.8	a	222.6
DD	39.1	24.1	196.6	102.1	65.6	151.9	143.1	a
EE	36.8	20.3	233.7	108.4	43.9	111.9	107.9	305.3
XX *	21.6	11.4	152.0	70.6	33.8	90.6	189.4	160.3
FF	31.1	19.9	78.8	88.1	24.4	95.0	62.9	196.6
SS	28.6	22.3	103.4	143.5	32.8	57.2	42.0	195.5
LL	27.2	24.5	230.7	116.2	13.6	70.9	51.4	153.8
OO	27·6	18.1 0.50	144.1	103.0	24.8	65.5	59.7	149.9
MM	29·8	17·8	*222·2	118.5	31.6	130.2	63.1	237.6
NN	30.5	19.5	218.3	113.1	30.5	103.6	86.5	191.9
GG	33.9	20.5	97.3	124.0	33.2	81.5	62.1	192.6
RR	28.8	18.5	118.6	124.5	25.2	81.4	48.1	189.2
PP	30.6	24.4	242.2	107.4	55.5	218.0	120.7	447.7
QQ	29.2	24.9	247.6	78.5	36.2	160.3	122.3	285.9
Al †	0.0	0.1	0.4	0.2	0.0	0.8	0.1	0.5
Cu †	0.1	14.0	0.3	12.4	0.1	8.3	0.7	10.0

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* XX, 500 days only.

† Aluminum and copper, 905 days only. The aluminum plates used contained: Cu, 0.08 per cent; Si, 0.50 per cent; Fe, 0.29 per cent.

Column headings:

1. Water } Quiescent } Plates continually wet
2. Brine
3. Water } Air-agitated
4. Brine

5. Water } Quiescent } Plates dried semi-weekly
6. Brine
7. Water } Air-agitated
8. Brine

E. A. Richardson and L. T. Richardson [13a] give data on the influence of copper, manganese, chromium, and some of their combinations, on the corrosion of iron and steel. Considerable division of opinion existed, before their tests were made, as to the effect of copper and manganese when added to commercially pure iron. It was thought that the probable effect of copper of decreasing the corrosion of iron might be increased by the addition of manganese or chromium. It had also been noted, in previous work, that copper makes iron red-short.

Atmospheric exposure tests were made and the method of judging the degree of corrosion was that adopted by the American Society for Testing Materials. It was concluded that:

(a) There is mutual action between manganese and copper in their effect upon atmospheric corrosion of iron. Copper alone reduced the corrosion of pure iron, and, to a still greater extent, the corrosion of steel, owing to the manganese in the steel.

(b) When manganese is replaced by chromium the effect is still more pronounced.

(c) The red-short range of iron, due to the presence of copper, is removed by either manganese or chromium.

(d) It is thought that there is some relation between this red-short range and resistance to atmospheric corrosion. Based upon this, the film or intergrain hypothesis is suggested to explain the corrosion resistance of these alloys.

These conclusions have caused considerable criticism; Aupperle contends:

(a) If sulfur is below 0.01 per cent even 0.5 per cent copper will not cause red-shortness in the metal.

(b) The manganese does not combine with the copper. Manganese sulphide is formed and pro 0.056 duces freedom from red-shortness.

(c) Chromium in amounts less than 0.5 per cent increases the rate of corrosion and in amounts from 0.5 per cent up to 35 per cent practically eliminates corrosion altogether. Silica has the same effect.

Speller states with regard to steel, copper-steel, and iron pipes that oxygen is the depolarizing agent. On the inside of the pipe is a large proportion of water and a small amount of oxygen while on the outside the conditions are reversed. The oxygen proportion present seems to govern the relative rates of corrosion of these materials.

C. F. Burgess and J. Ashton[43b] also describe corrosion tests made on alloys, in this case of electrolytic iron. The tests, which were run only on alloys that would readily forge into shape, gave the results shown in the following table:

		Acid Corrosion	Atmospheric Corrosion	
		G. per sq. dcm.	Lb. per sq. ft. per year	Kg. per sq. meter per yr.
Electrolytic Iron		1.30	0.1025	0.499
	Per Cent			
Aluminum	0.067	0·628	0.110	0.513
"	1.333	0.760	0.080	0.39
Arsenic	0.292	0.448	0.083	0.405
"	0.430	0.815	0.0703	0.343
"	0.951	0.405	0.0870	0·425
"	1 810	0.131	0.072	0.352
"	3.862	0.086	0.064	0.312
"	4.141	0.102	0.074	0.361
"	3.562	0·144	0.063	0.306
Cobalt	1.035	0.705	0.049	0.239
"	2.000	1.02	0.070	0.342
"	4.055	0.356	0.042	0.205
"	5.052	0.257	0.042	0·205
Copper	0.089	0.178	0.052	0.254
"	0.202	0.095	0.039	0.190
"	0.422	0.059	0.055	0.268
"	0.592	0·112	0.050	0.234
"	0.804	0.104	0.053	0.259
"	1.006	0.067	0.046	0.225
"	1.51	0.147	0.046	0.225
"	2.005	0.091	0.051	0·249
"	3.99	0.093	0.035	0.171
"	5.07	0.087	0.031	0.151
"	6.16	0.143	0.041	0.200
"	7.05	0·186	0.033	0.161
Lead	0.061	1.30	0.056	0.273

	Per Cent	Acid Corrosion G. per sq. dcm.	Atmospheric Corrosion Lb. per sq. ft. per year	Kg. per sq. meter per yr.
Manganese	0.505	0.56	0.055	0.268
"	1.00	0.52	0.080	0.390
"	2.00	0.725	0.062	0.302
"	3.00	1.11	0.067	0.327
"	10.419	0.352	0.089	0.435
Nickel	0.27	0.633	0.059	0.288
"	0.56	0.547	0.071	0.347
"	1.07	0.507	0.058	0.283
"	1.93	0.192	0.023	0.112
"	7.05	0.226	0.038	0.185
"	8.17	0.125	0.029	0.141
"	10.20	0.091	0.027	0.132
"	11.20	0.123	0.027	0.132
"	12.07	0.084	0.024	0.117
"	13.01	0.237	0.031	0.151
"	19.21	0.072	0.018	0.088
"	22.11	0.0254	0.020	0.098
"	25.20	0.054	0.023	0.112
"	26.40	0.554	0.021	0.102
"	28.42	0.155	0.021	0.102
"	35.00	0.183	0.018	0.088
"	47.08	0.160	0.0126	0.062
"	75.06	0.049	0.0044	0.0215
Selenium	0.017	0.190	0.1385	0.676
Silicon	0.233	1.63	0.104	0.500
"	0.603	1.19	0.076	0.370
"	1.033	0.85	0.106	0.518
"	1.897	0.80	0.124	0.606
"	2.826	1.27	0.134	0.635
Silver	0.281	1.02	0.065	0.317
"	0.402	1.76	0.090	0.430
"	0.581	1.34	0.073	0.356
"	0.601	1.17	0.092	0.450
Tin	0.288	0.284	0.069	0.337
"	0.342	0.350	0.039	0.190
"	0.686	0.380	0.049	0.239
"	1.568	1.03	0.058	0.283
Tungsten	0.406	0.363	0.076	0.371
"	0.025	0.088	0.062	0.302
"	2.334	0.086	0.062	0.302
"	3.553	0.332	0.063	0.308
"	5.082	0.304	0.060	0.293
"	9.849	0.398	0.040	0.195
"	13.641	0.365	0.049	0.239
"	23.866	0.183	0.044	0.215
Various grades of low carbon iron and steel				0.300-0.73
High Carbon Steel				0.278
Cast iron—scale removed				0.770

This work was criticized and the following points brought out:—

(a) Tests the results of which depend on re-weighing the specimen are not reliable. (A specimen rusting more evenly and losing weight slowly all over its surface shows up worse on weight records than another piece rusting and pit holing but not losing so much weight. Here is great danger of error!)

(b) Manganese oxide, not metallic manganese, is a harmful constituent. Switches and frogs of the Boston trolley system, made of manganese steel, remain bright after rain, whereas ordinary steel rails rust rapidly.

(c) Electrolytic iron cannot be compared with other forms of metal owing to its hydrogen content.

(d) These properties are due more to oxygen than to hydrogen.

(e) Once corrosion commences, rust overbalances all other influences within the metal.

(f) Organic matter in water causes rust to take the form of an impenetrable film or lining and causes corrosion to cease within a few months.

Corrosion tests were conducted by E. A. Fisher, City Engineer of Rochester, N. Y., on steel, wrought iron, ingot iron, and steel with known amounts of copper, to determine the influence of mill scale on the pitting of steel.[43c]

Finding that the usual accelerated tests were unreliable for this particular problem, corrosion stimulated by electricity was employed. Actual service conditions were not reproduced, the currents used being much stronger than those set up by galvanic action, though corrosion was enabled to take place in water and weak solutions such as are found in pipe lines carrying sewage. Possible differences in potential of mill scale to metal were investigated as an index to pitting and an index of corrosion uniformity established. The actual immersion tests proved the theory to be correct inasmuch as the tendency to uniform corrosion varied with the index of uniformity.

The obtained results indicated:

(a) Mill scale is an important factor in the formation of pits.

(b) Wrought iron has the tendency to pit less than steel.

(c) Ingot iron is intermediate between the two, but resembles steel more nearly than it does wrought iron.

(d) Steels containing copper differ but slightly among themselves, and from steel that contains no copper, in their tendency to form pits.

(e) To protect steel or ingot iron against failure by pitting the best remedy is the removal of the mill scale.

In a discussion of this paper the following points were brought out:

(a) The nature of mill scale depends largely on the temperature at which the metal is rolled, the amount of water used, the type of mill, the cooling, the use of salt, etc., so that unless the two classes of materials compared were rolled on the same mill and under the same conditions of heating, rolling, and cooling, a comparison cannot well be made.

(b) The steel had a black scale and the iron one of reddish brown. The latter might have been due to water running over the rolls at time of rolling so that it could not be considered a regular characteristic of the metal.

(c) Actual durability under hard service is a better indicator than experiments in the laboratory. An instance was given of two conduits supplying the city reservoirs of Rochester, one of wrought iron and the other of steel. After 25 years' service the wrought iron conduit showed six or seven leaks. After 15 years' service the steel conduit showed 160 rust holes and 450 additional ones had appeared to date (1912).

The effect of coal gas on the corrosion of wrought iron pipe buried in the earth is described by Dudley. His tests show that in earth alone the corrosion was approximately twice as rapid as in earth saturated with coal gas.[43d]

The sherardizing process is a method of dry galvanizing in which iron or steel articles are coated with zinc by being heated in zinc dust in closed receptacles; it is neither practical, nor useful, for the coating of other metals. A thorough investigation of the resistance of the coating to corrosion seems to justify the following conclusions:[43e]

(a) It resists atmospheric corrosion two or three times as well as does ordinary galvanizing of the same thickness.

(b) In structural work, in which bare iron and galvanized surfaces are often in contact, a sherardized surface has over five times the life of a galvanized surface.

(c) The life of a well sherardized machine used outdoors is practically as long as that of the machine when used indoors.

(d) The life of the coating is much improved by dipping it in a weak solution of paraffin in petroleum.

(e) Liquids act on the coating more than gases.

(f) Sherardized iron will outlast galvanized iron in nearly neutral liquids.

(g) The electric potential of the deposit is nearer that of iron than it is that of pure zinc and that part of the coating which is closest to the surface is still nearer that of iron. Thus, the action of acid liquor upon the deposit is selective, the thicker deposits being attacked first. The life of the coating in acid depends on the amount of zinc present and local action is largely absent. The solution takes place at a very even rate.

The effect of the process on tensile strength is determined by the entire removal of all mechanical stresses, and consequently of any weakness or strength due to them. In the case of wire and sheet this strength can be returned after sherardizing by drawing or rolling at the proper temperatures. The process distinctly improves the strength of chain and forged materials by removing the irregular stresses produced in forgings.

Nickel plated iron is satisfactory indoors but rusts outdoors, as does brass plated steel used for cheap builders' hardware. Extensive commercial demand exists for durable brass plate on steel.[43f] According to Metal Industry:[43g] "An electro-deposit of zinc on steel or iron is the only one that will withstand atmospheric conditions for any length of time and a demand is now being made for hardware that has received an electro-deposit of zinc before being plated with any other material for ornamental purposes, such as nickel, copper, brass or bronze. This double coating gives good service and is the only satisfactory one for hardware which is exposed to the weather."

This method is also used in manufacture of corset "steels" which are plated first with zinc and then with tin or nickel.

Zinc covered iron or galvanized iron possesses the advantage that if a hole forms, a cell is formed between coating and iron. Zinc alone being electropositive to iron, the iron acts as cathode and is protected from corrosion.

Siedler[43g] states that galvanized iron is destroyed very actively by acid vapors, and emphasizes the part played by soot as a catalyst. Galvanized iron appeared the most suitable material for floats used in the float valves which regulate the flow of acid sludges. Galvanized iron, wrought iron and copper were immersed in oil at ordinary mill temperatures.[43h]

Data follow on the corrosion of various metals by a number of different reagents, but two observations on the corrosion of iron may be noted here. In a synthetic phenol plant crude phenol mother liquors, consisting of a concentrated solution of sodium sulfate and bisulfite saturated with phenol and containing some suspended phenol, dissolved cast iron at 25° at a rate of 2.8 g. per sq. m. per hour.[29] Iron pipes laid in clays rich in calcium sulfate are especially prone to corrosion owing to the increased acidity of the water caused by a series of ionic reactions. According to Medinger the relatively large amount of calcium ion, $Ca^{\cdot\cdot}$, due to dissolved $CaSO_4$ represses the ionization of calcium bicarbonate, always present in water in lime soils, and thus reduces the concentration of bicarbonate ion, HCO_3', produced in the reaction

$$Ca(HCO_3)_2 \longrightarrow Ca^{\cdot\cdot} + 2HCO_3'.$$

Since there is always carbonic acid present in water exposed to the carbon dioxide of the air, the decrease in the concentration of bicarbonate iron causes an increase in the concentration of the hydrogen ion formed in the reaction

$$H_2CO_3 \longrightarrow H^{\cdot} + HCO_3'$$

and thus increases the acidity of the water.[30]

Storage tanks for ammonium nitrate solutions were formerly made of wood, but boiler plate tanks have been substituted because of their greater durability in spite of their rusting; the rust suspended in the solution has, in fact, a certain advantage in that it tends to neutralize any acidity that may develop in the course of storage or use. Ammonium nitrate solutions containing much ammonium chloride corrode wrought iron and steel strongly, but cast iron is sufficiently resistant for use with such solutions.[31]

The action of a number of corrosive solutions on a commercial ferro-silicon alloy is shown in the following table:[6]

Salt	Solution Strength Per Cent	Temp.	Loss $g/m^2/hr$
Copper sulfate	17	Room	0.0001
" "	67	80-85° C.	0.0030
Ferric sulfate	Saturated	Room	0.0005
Ferrous chloride	39	Room	0.0444
Sodium chloride	16	80°	None

From another test of 120 days' duration the following data are taken showing corrosion in terms of depth in centimeters per year.

Solution	Depth of Corrosion
25% $CuSO_4.5H_2O$	0.0000566
27% NH_4Cl	248
48% Fe_2Cl_6	100
87% H_3PO_4	0477

The non-corroding steel mentioned above,[5b] manufactured by the Crucible Steel Co., is said to be entirely unaffected by 20 per cent silver nitrate solution, 1 : 1000 mercuric chloride, boiling liquid air and water saturated with carbon dioxide. It is discolored slightly by saturated salt solutions, somewhat attacked by saturated alum, and attacked by sodium cyanide one-third as readily as wrought iron or copper. Its comparative resistance to scaling is shown in the table that follows :

Comparative Resistances to Scaling	Loss	Gain
Grade 2	None	4.8 mg.
" 3	"	4.6 "
" 4	0.3	None
" 5	None	"
Monel Metal	338.	"
95% Nickel	15.	Adherent scale
High Cr, Ni Steel	57.1	
Grade A Steel	None	1.2
High Cr Steel	520.5	
Copper Steel	967·4	

Copper will not plate on it in either neutral or acid solution of copper sulphate at room or at boiling temperatures. It suffered no loss after immersion for 24 hours in water through which oxygen was bubbling. A similar test using wrought iron and Monel metal showed a loss of 7.20 and 0.77 mg. respectively.

Commercially Pure Iron.—Samples of commercially pure iron were compared with samples of steel in tests of their resistance to corrosion by ammonium chloride, magnesium chloride, aluminum sulfate and ammonium nitrate. The analysis of the samples gave the following results:

ANALYSIS OF SAMPLES

	Per Cents				
	S	P	C	Mn	Cu
Commercially pure iron in—					
ammonium chloride..........	0.020	0.007	0.010	0.025	0.078
magnesium "	0.020	0.006	0.010	0.018	0.020
aluminum sulfate............	0.015	0.006	0.010	0.012	0.018
ammonium nitrate...........	0.036	0.006	0.010	0.021	0.040
Steel in—					
ammonium chloride..........	0.025	0.004	0.050	0.280	0.200
magnesium "	0.035	0.013	0.080	0.400	0.281
aluminum sulfate............	0.048	0.077	0.140	0.288	0.372
ammonium nitrate...........	0.043	0.077	0.100	0.280	0.248

ACTION OF SALT SOLUTIONS AT ROOM TEMPERATURE

	Salt	Concentration Per Cent	Duration, Days	Total Loss, g/m²	Average Loss, g/m²/hour
Commercially pure iron	NH_4Cl	3	420	1181	0.102
	$MgCl_2$	5	420	206	0.020
	$Al_2(SO_4)_3$	20	12	21·4	0.074
	NH_4NO_3	3	191	2665	0.581
Steel	NH_4Cl	3	420	1337	0.132
	$MgCl_2$	5	420	259.4	0.026
	$Al_2(SO_4)_3$	20	12	1782	6.18
	NH_4NO_3	3	191	4881	1.06

There is a remarkable difference in the behavior of the two metals towards aluminum sulfate, and a less marked difference with ammonium nitrate; in all four cases the pure iron showed some superiority.

The conditions which favor the corrosion of aluminum are different from those which favor the corrosion of iron both because of the different chemical characteristics of aluminum and because of the different common impurities of the two metals. Conductivity water (that is, distilled water of the highest purity) reacts with ordinary aluminum, coating it with a yellow film and dissolving some of the metal colloidally. At 100° this reaction appears in several hours, but at room temperature is observable in about three months. The layer contains $Al(OH)_3$, Al_2O_3, a little iron, and probably silicon; hydrogen is evolved in appreciable quantities. No action is observable with pure aluminum, which in the experiments had the following composition:

	Per Cent
Al	99.37
Fe	0.070
Si	0.401
Ca	Traces
Na	0.039

but if a piece of polished iron was immersed in the water during the action, a black layer of oxides of iron and aluminum was deposited on the aluminum. An alloy containing 14.49 per cent Fe behaved in the same way except that the layer was chiefly iron.[32]

As might be expected, sodium in aluminum increases its tendency to corrosion by water. In sea water an alloy containing 10 per cent Fe has only $\frac{1}{7}$ the resistance to corrosion of aluminum alone; the addition of 1.5 per cent tungsten improved this slightly, but the substitution of nickel or cobalt for part of the iron lessened the resistance.[33] The value of pure aluminum has been recognized in brewing, where nearly all trouble due to corrosion of aluminum vats has been eliminated by the use of metal of high purity.[34]

Aluminum bronze, containing 5-12 per cent Al, is easily fusible, and has mechanical and chemical resistance surpassing all other bronzes.[35]

The widespread use of tin as a coating for iron in tin plate is due to its resistance to corrosion under ordinary atmospheric conditions, but, as explained above, it has the disadvantage that where once the coating has been destroyed at any point, the corrosion of the iron is increased. On account of its extended use in containers as well as in chemical apparatus, a knowledge of the behavior of tin towards pharmaceutical chemicals is of importance. If tin tubes are boiled in water, 1 per cent sodium chloride, or 0.5 per cent phenol, some of the metal is colloidally dissolved, but when the tubes are not in contact, the following solutions dissolve none of it: distilled water, 1 per cent sodium chloride, or 0.5 per cent phenol, 1 per cent morphine hydrochloride, 0.01 per cent atropine sulfate, 0.1 per cent cocaine hydrochloride, 5 per cent sodium cacodylate, 0.1 per cent strychnine nitrate, 25 per cent caffeine-sodium benzoate, 20 per cent caffeine-sodium salicylate, Digalene, 1 per cent novocaine with or without phenol. No tin is dissolved by distilled water at 50-150° if there is no rubbing of the tin. A 0.35 per cent solution of $Na_2HAsO_4.7H_2O$ dissolves some tin.[36]

Copper is not acted on by water alone nor by dry oxygen, but in moist air it is attacked with the formation of cuprous oxide and a green basic carbonate. In sea water $Cu_4(OH)_6Cl_2.H_2O$ is formed.[1]

Sodium nitrite ($NaNO_2$) solutions saturated with carbon dioxide (CO_2) react with copper, some of the products being NO,

N_2O and $NaNO_3$. Iron acts similarly, and cobalt forms $CoNa(NO_2)_4$.[37]

B. E. Curry[11] investigated the corrosion of bronzes very thoroughly. The test pieces were made from very pure electrolytic copper and 99.99 per cent tin, melted and cast in graphite, 8.5 cm. long and 0.8 cm. in diameter.

In a 20 per cent solution of sodium persulfate, the tendency is to dissolve tin, and so the effect varies according to the phases present in tin bronze alloys. Shepherd and Blough[45] have shown that five solid phases occur in bronzes annealed between 200 and 400°. From 100 per cent to 87 per cent copper exists a series of solid solutions– the α crystals; from 87 per cent to 74.5 per cent, the alloys consist of mixtures of copper and δ crystals, another series of solid solutions. From 74.5 per cent to 67 per cent, the δ crystals (which Heycock and Neville[46] thought to be the compound Cu_4Sn) and between 67 per cent and 61.3 per cent mixtures of δ crystals with the compound Cu_3Sn, which occurs pure at 61.3 per cent copper. From 61.3 per cent to 41 per cent Cu_3Sn and ε crystals, another series of solid solutions, coexist; from 41 per cent to 40 per cent ε crystals alone, and finally, from 40 per cent on mixtures of ε crystals and pure Sn.). In the persulfate corrosion tests the 95 per cent piece was eaten out in deep holes, the surface remaining clean, bright and free from oxide. The 90 per cent piece was less affected, the surface being only slightly pitted. The 85 per cent and 65 per cent pieces were tin-rich on the surface. The 65 per cent and 50 per cent pieces were coated with oxide but only slightly corroded. The 25 per cent pieces were severely pitted. The quantitative results were:

20 PER CENT SODIUM PERSULFATE SOLUTION

Per Cent Cu in Test Piece	Corrosion in G.	G. Cu Corroded	Per Cent Cu Corroded
95	4.1613	3.9490	94.9
90	0.6260	0.5645	90.2
80	0.2748	0.2617	95.2
65	0.0664	0.0620	93.3
50	0.0085	0.0060	70.5
25	0.1256	0.0098	7.8

Another series of tests was made with a 20 per cent solution of sodium persulfate made strongly alkaline with caustic soda. The test-pieces were allowed to stand in the solutions for sixteen days. The data are given in the following table:

20 PER CENT SODIUM PERSULFATE + EXCESS NaOH

Per Cent Cu in Test	Corrosion in G.	G. Cu Corroded	Per Cent Cu Corroded
95	2.4075	2.3038	95.2
90	1.5424	1.3924	90.3
80	0.0829	0.0746	90.0
65	0.0063	0.0047	74.6
25	1.6478	0.2558	15.5

In a 7 per cent sodium chloride solution, agitated with air continuously for from 5 to 9 weeks it was found that corrosion was relatively light, the crystals dissolving most rapidly. The following table gives the quantitative data:

7 PER CENT SODIUM CHLORIDE SOLUTION

Per Cent Cu in Test	Corrosion in G.	G. Cu Corroded	Per Cent Cu Corroded
95	.0954	.0916	96.0
85	.0534	.0480	88.2
70	.0563	.0390	69.4
65	.0450	.0296	65.8
60	.0400	.0240	60.2
50	.0430	.0120	51.0
25	.0360	.0022	6.0

Curry ran electrolytic corrosion tests with the same solutions and found that the results conform closely to those for chemical corrosion, except that in every case the time is shorter. This fits into the general electrolytic theory of corrosion very nicely and Curry's electrolytic results are likely to be good indications of the resistivity to chemical corrosion of the various bronzes. According to these results bronzes with less than 40 per cent copper corrode rapidly in dilute nitrate solutions, but a bronze with 75 per cent tin (almost pure δ crystals) forms a protecting film and corrodes very slowly. Bronzes with from 70 per cent to 40 per cent copper do not corrode in sulfate solutions. With less than 40 per cent copper all the bronzes corrode in sulfate solutions. Bronzes with approximately 85 per cent copper resist acetate solutions well; low copper bronzes less well. The 15 per cent copper bronze corrodes three times as fast as the 35 per cent copper. The bronzes do not corrode at all in carbonate solutions. Curry says "It is quite evident that the green carbonate that forms on the surface of bronze exposed to the air must first dissolve as some other salt which is afterwards changed to a carbonate." All bronzes corrode in alkaline tartrate solutions, and in acid oxalate solutions.

The above results must not be taken as being more than indications from a practical chemical engineering viewpoint, since wherever the resistivity is due to film formation, corrosion will obviously proceed more rapidly in a part of a machine, for example, than in a tank, and more rapidly in either than in a test piece.

A large condenser pump that had to withstand the corrosive action of sulfur water was cast of a copper alloy containing

	Per Cent
Cu	76
Pb	14
Sn	8.5
Zn	1.5

The weight of the finished casting was 7800 lbs.; the pump was designed to operate against a pressure of 200 lbs. per sq. in.[38]

A corrosion-resistant alloy with a lead base, called Frary metal, has recently been put on the market by the United Lead Company. Its composition is

	Per Cent
Pb	98
Ca	1.2
Ba	0.7
Hg	0.1-0.2

It is harder than lead, its Brinnell number being 20-30, but is not brittle, and it has a tensile strength of 13,000 lbs.

Pure distilled water was used in a series of experiments[39] on lead, steel, copper, zinc, tin, and silver. Thin sheets of the metals were immersed in twice distilled water contained in Jena glass flasks, and observations made of the change in conductivity of the water, loss in weight of the metal and change in appearance of the metal surfaces. There was no corrosion of tin or silver; steel was considerably corroded but the water in which it was showed little increase in conductivity; the water in which the zinc was immersed showed the greatest increase in conductivity, and the conductivity increased at a greater rate the last ten than the first twenty days of the thirty days of the test.

Water used repeatedly in sugar plants becomes strongly acid and strongly etches iron apparatus with which it comes in contact. Comparative tests made with water having an acid content equivalent to 3.5 c.c. 0.1 normal NaOH solution per liter showed that its action on brass and iron was respectively 1.176 and 46.9 times its action on bronze. At prevailing pre-war prices it was 21 times as expensive to use iron as bronze in the apparatus in question.[40]

Monel metal proved in one series of corrosion tests to be about equal in resistance to phosphor-, Tobin and manganese bronzes, but was superior to these in appearance at the end of the test. The metal samples were buried for six months in ground which was wetted periodically with dilute corrosive salt solutions. The losses in weight were:[41]

	Per Cent		Per Cent
Muntz metal	0.33	Monel metal	0.12
Phosphor-bronze	0.09	Manganese bronze	0.12
Tobin bronze	0.11	Steel	1.04

Analyses of Monel metal range in general as follows: nickel, 66-70 per cent; copper 23-28 per cent.[42]

Monel metal takes and retains a finish almost identical with that of pure nickel and is for this reason much used for small fittings, trimmings and stampings, for golf-club heads and for table cutlery. This property in conjunction with its resistance to corrosion by substances used in preparation of foods and in washing have made it valuable for the construction of certain cooking utensils and for washing tanks, cream separator machinery, etc.

Because of its relative incorrodibility it has been used to some extent for roofing materials. The roof of the Pennsylvania Terminal in New York City is covered with Monel metal sheet, selected because of its superiority over other roofing materials demonstrated during a ten-year test. It is also used for window screens for the same reason.

Both rods and castings are used to a large extent in the manufacture of pumps, pump liners, rods, valves, etc., for handling sea water, mine waters and acid and alkaline corrosive solutions generally.

The resistance of the alloy to steam erosion and its strength at high temperatures, which seems to be higher than that of the steels or bronzes, have caused its extensive application in the production of steam pressure valves and steam turbine blading. For these purposes it is well suited by further reason of the fact that its thermal expansivity is approximately equal to that of steel, with which it is usually associated in such construction.

Marine propellers have been cast of Monel metal. In connection with its quite widespread use in naval construction it may be recalled that the steam yacht Sea-Call was covered with Monel metal sheathing, in this particular case unsuccessfully, for the reason that the galvanic action between it and the exposed steel parts of the hull caused accelerated corrosion of the latter.

Monel metal is remarkably resistant to oxidation even at high temperatures (750° C.) and is used for electrical resistance and spark-plug wire and other parts exposed to high temperatures. Monel metal is made up into screens of various types, into filter cloth for corrosive liquids, and into screw machine products of all kinds.[9a]

Monel metal resists well the corrosive action of sea water, solutions of alum, many neutral sulfates and chlorides, and many technical solutions such as those of photographic chemicals. It resists ferrous sulfate fairly well, but not ferric chloride nor fused or dissolved potassium cyanide.

The behavior of stellite (see p. 52) towards some salt solutions is shown in the table on page 90.[10a]

Heating the solutions to boiling did not increase the action of mercuric chloride nor of silver nitrate, but it did increase the action of potassium permanganate and it increased the deposit of copper by copper sulfate on the first two samples of the table.

The action of dilute solutions of three salts, which are slightly acid in solution owing to hydrolysis, on eight metals is given in the following table; the analyses of the metals and a description

ACTION OF SALT SOLUTIONS ON STELLITE

	Mercuric Chloride 5 Per Cent	Silver Nitrate 10 Per Cent	Copper Sulfate 10 Per Cent	Potassium Permanganate 5 Per Cent	Sodium Hypochloride U. S. P.
Cast festel stellite	Very slight tarnish	No change	Plated with copper	Covered with iridescent film	Slight tarnish at edges
Hammered festel stellite	Very slight tarnish	No change	Plated with copper	Covered with iridescent film	Slight tarnish at edges
Cast soft malleable stellite	Very slight tarnish	No change	No change	Covered with iridescent film	Slightly spotted, loss negligible
Hammered soft malleable stellite	No change	No change	No change	Covered with iridescent film	Slightly spotted, loss negligible
Cast hard malleable stellite	No change	No change	No change	Covered with iridescent film	Slightly spotted, loss negligible
Hammered hard malleable stellite	No change	No change	No change	Covered with iridescent film	Slightly spotted, loss negligible
No. 2 stellite	No change	No change	No change	Covered with iridescent film	Slightly spotted, loss negligible
No. 3 stellite	No change	No change	No change	Covered with iridescent film	Slightly spotted, loss negligible
No. 4 stellite	No change	No change	No change	Covered with iridescent film	Slightly spotted, loss negligible

of the experimental conditions have been given above[8] (pp. 29 and 48):

ACTION OF 0.2 N SALT SOLUTIONS ON METALS AT 17–20°

LOSS IN GRAMS PER SQUARE METER PER HOUR

A. Action of ½ liter solution renewed daily for 7 days.

Metal	$MgCl_2$	$CaCl_2$	NaCl
Zinc	0.57	0.21	0.06
Cast iron	0.51	0.12	0.06
Wrought iron	0.51	0.18	0.15
Aluminum	0.10	0.03	0.00
Lead	0.33	0.24	0.01
Copper	0.15	0.12	0.01
Tin	0.10	0.08	0.00
Nickel	0.03	0.05	0.00

B. Action of ½ liter solution for 28 days, not renewed.

Metal	$MgCl_2$	$CaCl_2$	NaCl
Zinc	0.04	0.03	0.03
Cast iron	0.07	0.03	0.04
Wrought iron	0.06	0.04	0.04
Aluminum	0.02	0.00	0.00
Lead	0.02	0.02	0.01
Copper	0.01	0.01	0.00
Tin	0.01	0.01	0.01
Nickel	0.01	0.01	0.00

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IV. Acids and Non-Metallic Materials.

To cover exhaustively all the known reactions between acids and non-metallic industrial or engineering materials is outside the range of this book; instead of this, an attempt will be made to present some of the general characteristics of the more important materials together with such specific data as are at the same time available and useful.

The materials coming under this heading may be conveniently divided into two general groups which have very dissimilar characteristics; inorganic materials, like concrete and stone; organic materials like wood, rubber, cloth of different fibers, etc. The attack of acids on materials belonging to the inorganic group is usually an ionic reaction resulting in the solution of some ingredient necessary to the strength of the material, as, for example, the solution of lime stone in an acid:

$$CaCO_3 + 2H^{\cdot} = Ca^{\cdot\cdot} + H_2O + CO_2.$$

On the second class, i. e. organic materials, the attack may be as various in kind as are the materials,—a hydrolysis, dehydration, oxidation, nitration, sulfonation, etc.

Concrete and Cement.

Portland cement and, therefore, concrete made from it, though fairly resistant to alkalies, are readily attacked by strong acids, and the continued action of very dilute solutions of acids has in time a deleterious effect; even weak acids and water rich in carbon dioxide are harmful.

In the case of sulfuric acid the destruction of the cement is due to the formation of calcium sulfate, which may be hydrated ($CaSO_4.2H_2O$); the volume changes involved in the crystallization of this substance cause a blistering or cracking of the cement especially if it is mixed with sand. Neat cement may become incrusted with a protective coating of calcium sulfate owing to its originally smaller permeability.[1] Blast furnace slag cements are more resistant to dilute (1-1.5 per cent) sulfuric acid, while iron-portland cements are less resistant than ordinary portland cement.

A correspondent in Concrete[14] relates an experience with two concrete tanks 2 ft. wide, 3 ft. long, 1¼ ft. deep with 4 in. reinforced sides and bottom, mixture 1:2:4, used to contain 16 per cent sulfuric acid. At end of 7 days it was noted that surface was blistered and acid had eaten into the concrete in spots to a depth of ⅜ in. The second tank of the same design was lined with pure cement ¾ in. deep. At the end of 5 days the tank was badly scarred and the cement was eaten into ¾ in. in places. A layer of precipitated calcium sulphate 2 in. thick was formed.

The action of sulfate solutions, e. g. sodium and magnesium sulfates, is similar to that of dilute sulfuric acid. In experiments where two portland and one blast-furnace slag cement were kept immersed in sodium and magnesium sulfate solutions of 0.1-20 per cent concentration, the slag cement was more resistant. In the more concentrated solutions the destruction was chiefly due to the formation of gypsum.[2]

Acids that form soluble salts with lime are even more destructive since they leach out part of the lime content of the cement or concrete. The action of water rich in carbon dioxide is slow on account of the extreme weakness of carbonic acid, but it does nevertheless have the effect of removing lime as the soluble salt $CaH_2(CO_3)_2$,[5] and organic acids act in much the same way, though not necessarily forming a so-called acid salt. The failure of the concrete of sewers has been attributed indirectly to the action of hydrogen sulfide produced by decaying organic matter; this is oxidized by the oxygen of the air to sulfuric acid, the slow action of which in small amounts causes the damage.

H. J. M. Creighton[2a] has described examples of failures in reinforced concrete due to the corrosion of iron reinforcements by brine, and discussed the probable reactions which occur when iron comes in contact with a salt solution. From results of his investigations he concludes:

(1) All concrete which is not waterproofed in some way is more or less porous to water and brine.

(2) Brine rapidly softens the surface of concrete, and therefore, more easily penetrates to the reinforcements on which it exerts a disintegrating action that, owing to the attendant expansion gradually weakens the concrete, causing it to crack and split and in some cases to fall away from the reinforcements.

(3) The more porous the concrete the more rapid the disintegration of the reinforcements through the action of the brine.

(4) Reinforced concrete floors which come in contact with brine will gradually develop leaks. This will be followed by incrustations of discolored salt on the underside, where, later, iron stained hair cracks will develop running parallel to the reinforcements. As deterioration progresses the cracks will widen, and, owing to the great expansive force of the accumulating iron oxide, the concrete will be gradually pushed from the corroded reinforcements and ultimately fall.

(5) The permanence and durability of reinforced concrete in contact with sea water is a matter of considerable doubt unless the sea water is prevented from coming in contact with the re-

inforcements. Such prevention may be effected by coating the reinforcements with protective paints or by applying to the outer surface of the concrete some material which will render it waterproof. Most of the substances used for this purpose are not satisfactory and it is suggested that a coating of the concrete with a very thin layer of metal by means of the Schoop Metal Spraying Process might be beneficial.

Concrete tanks for photographic solutions are said to be entirely satisfactory when coated with any good commercial water-and-acid-proof paint of asphaltic nature.[2b] Concrete without such a coating will not stand photographic solutions, the sulphites particularly affecting portland cement. Paraffin coatings are unsuccessful. The Eastman Kodak Company find concrete tanks satisfactory, made as follows: Rich mortar is applied to ½ in. galvanized iron mesh, finished smooth inside, lined with waterproof paper and then coated with asphalt paint.[2c]

Sugar solutions of 20 per cent sugar content in contact with concrete dissolve iron, aluminum and calcium from the concrete and become discolored, a fact which makes the use of concrete for the handling of such solutions of questionable value, especially when the solutions remain for a considerable time in contact with the concrete; molasses behaves in the same way. Glycerol behaves similarly towards the aluminum and calcium but does not affect the iron.

According to the same author gas liquors containing ammonium sulfide attack concrete unless air is excluded, the sulfide forming ferrous sulfide with the iron of the concrete, which is oxidized to ferric sulfate.[3]

Concrete may be protected in many ways; a detailed consideration of these will be found in Chapter VIII, but they may be summarized here as follows: 1. Membrane method; tar, asphalt, etc., applied in conjunction with membranes of felt, burlap, etc. 2. Brush application of neutral hydrocarbons. 3. Brush application of an acid resin which forms insoluble resin soaps with the lime of the concrete integral with its surface. 4. Addition of not more than 2 per cent dry powder to increase density of concrete. 5. Application of a brush coating or spray of a silico fluoride which precipitates an oil- and waterproof deposit of silica in interstices. 6. Coating with two solutions that react to form a precipitate in interstices which prevents penetration and attack by corrosive liquids.[1]

The Trus-Con Laboratories, Detroit, state that it is impossible to incorporate any material with concrete to render it acid-resistant. A perfect coating is necessary. They use a mixture of synthetic resins called Baracide.

Merernastic * enamel or a Mexican blown asphalt [obtained from U. S. Asphalt Refining Co., Baltimore] of melting point 250-300° F. has been used successfully. A priming solution is

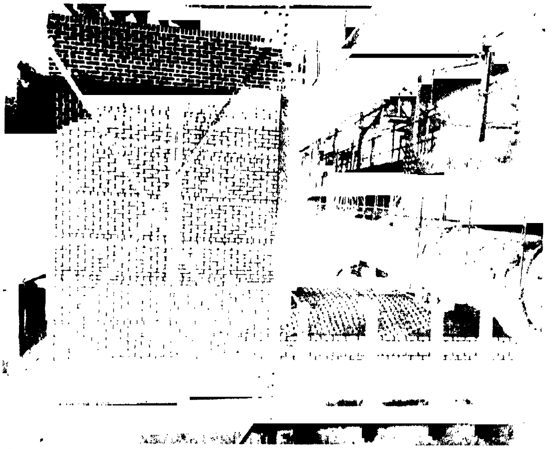
* Wailes-Dove-Hermiston Co., New York.

supplied with the Meremastic enamel. For the blown asphalt a priming solution is made by dissolving a portion of the asphalt in benzol and thinning with turpentine substitute to thick paint consistency. Apply with an ordinary paint brush. When dry, but still sticky, apply the enamel. This will stand 16 per cent sulphuric acid or 20 per cent alkali at any temperature and 30 per cent alkali at room temperature.

Minbrite Mastic* ¼ in. thick in channels where liquid is in motion to $\frac{1}{16}$ in. in basins or tanks, has given excellent service. It can be applied cold, and over wet surfaces; it remains plastic when cold. It resisted hot concentrated nitric acid several months before being affected at all, and weak cold acids seem to have no effect.

Bricks, Tiles and Stoneware.

It follows from the above that floors and other structural parts likely to be exposed to the constant action of acids, as for example under wooden tanks containing acid solutions, should either not be of concrete or should be protected by some acid-proof material. Acid-proof tile floors are excellent.



Courtesy Chemical Construction Company

FIG. 12.—Example of Acid-proof Masonry Using Acid-proof Brick and Acid-proof "Acipruf" Cement.

The best acid-proof bricks are said to be of volvic lava,[6] and next to these comes so-called "chemical brick." This can be laid with a mortar of asbestos powder, sodium silicate and a filler like barytes, or floor tiles may be laid in molten sulfur. This is set by a preliminary treatment before use with acid, which precipitates insoluble silica from the soluble silicate used.

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* Nat. Roofing Co., Tonawanda, N. Y.

Excellent and very durable tanks for acids can be built by lining steel, iron or concrete tanks first with tar or asphalt and then with one or two layers of acid-proof brick, preferably glazed. The latter may be laid in ordinary mortar, if wide joints (say 6-7 mm.) are left and the mortar is not brought up to the surface of the bricks. The joints are filled with two successive layers of acid-proof cement, which is usually supplied by the manufacturer of the bricks, and when this is dry it is set by allowing the tank to stand for three days filled with 2 per cent sulfuric acid. If the tank is to be used for hot solutions whose temperatures would soften tar or asphalt, the layers of these must be omitted. Tanks of this construction will successfully resist hot 80 per cent sulfuric acid.[7]

In England bricks of Mold in Flintshire are used. This material analyzes:

	Per Cent		Per Cent
SiO_2	63.01	MgO	0.40
Al_2O_3	25.95	Na_2O	Trace
Fe_2O_3	6.49	K_2O	2.57
Mn_3O_4	0.75	Organic matter and water	0.9
CaO	0.83		

From the point of view of resistance to acids the most satisfactory material is "chemical stoneware," though because of its mechanical properties its use is avoided wherever a substitute of greater tensile strength and less brittleness can be used. Its disadvantages are the ease with which it is broken by mechanical shock or by sudden heat changes and the difficulty or impossibility of repairing it. In spite of these disadvantages, however, and because of its wonderful inertness towards almost all acids (hydrofluoric being the chief exception, since it attacks all silicious materials) "chemical" stoneware is widely used, and its manufacture has been developed to such a point that articles made of it range from small cocks through centrifugal and plunger pumps to one piece tanks of a thousand gallons capacity. The best clay for such stoneware is one rich in silica rather than alumina, and dense.[8] Failing this an artificial porcelain-like mixture may be used, containing 25-30 per cent felspar, 25-30 per cent best china clay, and 40-50 per cent quartz. It should be burnt to a clinker and glazed with 54 parts quartz, 84 parts felspar, 35 parts ground chalk, and 26 parts ground china clay.

Acid-proof stoneware varies in color from pale gray to ruddy brown according to the origin of the clay used in its manufacture. It is especially useful for carrying out nitrations in dilute acid, chlorinations, reactions with strong hydrochloric acid and all reactions in which all traces of metal must be avoided. Most reactions carried out in such apparatus must be on a comparatively small scale.

Stone as a construction material for apparatus is being replaced by manufactured materials. For such purposes slate is perhaps the most frequently used stone. An English slate recommended for chambers used in the Deacon chlorine process, in which common salt and manganese dioxide are heated with sulfuric acid, had the following composition:

	Per Cents		
SiO_2	61.26	to	58.91
Al_2O_3	20.49		23.08
Fe_2O_3	7.23		9.02
CaO	1.98		2.06
MgO	1.96		1.14
K_2O	2.18		1.92
Na_2O	2.38		1.02
Water	3.44		2.85

The presence of iron pyrites, which is absent from the above samples, is very objectionable in a slate designed for use in contact with acid solutions. While the action of dilute acids on well chosen slate is slight, they will in the course of time soften it; strong concentrated acids destroy it rapidly.[9]

Glass.

Glass, while used to only a small extent for commercial chemical operations, and then chiefly because of its transparency, is of paramount importance in the laboratory. It is too often used without regard to its solubility, and its attack by reagents often goes unnoticed because of its transparency. Tests of chemical glassware have shown that good glassware can be and is made for general use, but that for special purposes, especially for analytical work, the kind of glass used must be chosen with regard to the conditions of use.

In one series of tests[10] eight samples of laboratory glassware (500 c.c. Erlenmeyer flasks) were treated with 300 c.c. boiling solutions for three hours and with cold water for one week. The glasses, marked A to H, were of the following manufacture:

A, B, C, French	F, Kavalier, Bohemian
D, Jena	G, H, Thuringian
E, Kasna, Bohemian	

and had the following compositions:

	A	B	C	D	E	F
SiO_2	71.92	70.10	67.52	66.04	72.92	71.50
B_2O_3	None	None	4.98	8.02	1.96	3.94
P_2O_5	0.05	0.04	0.02	0.03	0.04	0.04
As, ^{5}S, Cl, F	None	None	None	None	None	None
PbO	None	4.94	None	None	None	None
Al_2O_3	0.51	0.58	0.54	1.05	0.32	0.50
FeO	0.35	0.28	0.25	0.38	0.20	0.21
MnO	Traces	0.66	None	0.40	Traces	Trace
ZnO	5.96	None	6.02	10.02	None	None
MgO	0.28	0.36	0.06	5.98	0.28	0.26
CaO	6.86	6.27	5.60	None	8.17	8.56
Na_2O	14.20	31.23	6.51	8.14	13.89	9.43
K_2O	None	5.64	8.52	Traces	2.27	5.54

Reagents under the conditions described above had the following effect:

TABLE

LOSS OF CHEMICAL GLASSWARE IN MILLIGRAMS

On Being Treated with 300 c.c. of Various Reagents at the Boiling Temperature for Three Hours

	A	B	C	D	E	F	G	H
Boiling water 1	5.5	3.0	2.0	4.0	8.0	6.0	5.0	10.0
" " 2	3.5	2.5	0.5	3.0	6.0	6.0	1.5	6.0
" " 3	3.5	2.5	0.5	2.5	11.0	7.0	1.0	5.0
Cold water *	0.0	0.0	0.5	0.0	1.0	0.5	0.5	1.0
HCl, 10%	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.5
NH_4Cl, 0.1 N	5.5	7.0	5.0	4.5	8.0	7.0	2.0	2.5

* Action for one week.

ACTION OF WATER AT HIGHER TEMPERATURES IN AN AUTOCLAVE

	A	B	C	D	E	F	G	H
120°	5.0	13.5	0.0	4.0	16.0	20.0	8.0	25.0
140°	8.0	42.0	9.0	9.0	72.0	74.0	3.5	49.0
160°	75.1	71.0	37.0	31.0	99.0	126.0	77.0	84.0

A comparison of several brands of American glass with well known foreign makes has been carried out by the Bureau of Standards.[11] The makes tested and the letters by which they are referred to in the following tables are:

A. Kavalier
B. Macbeth, Evans Glass Co.
C. Pyrex
D. Jena
E. Nonsol
F. Fry
G. Libbey

The glasses were found to have the following compositions. The variations to be expected between different samples of the same make are indicated by the analyss of the Jena beaker and flask.

	A	B	C	D *	D †	E	F	G
Al_2O_3	0.14	1.0	2.0	4.2	4.22	2.5	2.7	2.1
Fe_2O_3	0.08	0.35	0.25	0.25	0.27	0.23	0.42	0.44
ZnO	none	5.6	none	10.9	10.9	7.8	3.6	none
PbO	none	none	none	none	none	none	none	1.0
MnO	0.02	0.02	0.01	0.01	0.01	0.01	0.03	0.03
CaO	8.7	0.66	0.29	0.63	0.56	6.79	2.6	0.42
MgO	0.17	4.3	0.06	0.2	0.25	3.4	2.6	0.08
Na_2O	7.1	10.8	4.4	7.5	7.8	10.9	4.8	8.2
K_2O	7.9	0.30	0.20	0.37	0.31	0.30	1.5	0.67
SiO_2	75.9	73.0	80.5	64.7	64.7	67.3	68.6	75.9
B_2O_3	none	3.6	11.8	10.9	10.6	6.2	8.1	10.8
P_2O_5	0.08	none	none	none	none	none	none	none
SO_3	0.20	0.02	none	none	none	none	none	none
As_2O_5	trace	0.02	0.70	0.14	0.19	trace	0.18	0.36
Sb_2O_5	none	0.60	none	none	none	0.62	none	none

* Beaker.
† Flask.

Samples of these makes were tested for resistance to attack by different reagents and resistance to mechanical shock and sudden temperature changes, and from these tests the different glasses were graded as in the following table, where P indicates poor, F fair and G good; the numerical superscripts indicate a further grading where that is possible, 1 indicating greatest and 4 least resistance.

TABLE

GRADING OF LABORATORY GLASSWARE ACCORDING TO ITS RESISTANCE TO ATTACK

Make Tested	Water	Mineral Acids	Heat Shock	Mechanical Shock
A	P	G	P	P
B	G^3	G	P	P
C	G^2	G	G^1	G *
D	G^4	G	G^3	F
E	G^3	G	G^2	F
F	G^4	G	P	G
G	G^1	G	G^2	G

* Far superior to other samples tested.

A somewhat more extensive series of tests has recently been completed in England[12] covering 22 kinds of laboratory glassware, the names of 13 of which are published. Samples were submitted to a long series of carefully controlled tests (in many respects similar to those used in the experiments just mentioned), and the different makes graded according to the results obtained in those tests which were considered to simulate most nearly conditions obtaining in actual use. The criterion used in grading the different glasses was the loss in weight per unit area (in the tests with water the total loss in weight) during the tests. Flasks of as nearly the same size and shape as were obtainable were used in the tests, the conditions of which were as follows: 1. Two hundred c.c. water were boiled in each flask; 2. Flasks containing 250 c.c. water were heated to 183° C. in ¾ hour in an autoclave (pressure 10 kg. sq. cm.), held at that temperature 3 hours, and cooled down in 1 hour; 3. One hundred and fifty c.c. 20 per cent hydochloric acid were boiled in each flask for 1½ hours and the test repeated three times. The autoclave test was the most drastic, and even very resistant glasses showed etching and opalescence after undergoing it.

The letters used to indicate the various makes and the names of these makes or origin of the glass as far as known are:

A. Pre-war Jena
B. not given
C. British
D. "
E. "
F.-J. not given
K. Japanese
L. Nonsol, American

M. Insolo, American
N. Fry, "
O. Pyrex, "
P. Resistance 'R', German
Q. Kohn, Elberfeld, "
R. Kavalier, Austrian
S. unmarked, German
T. Insol, American
U. Zsuola, German
V. Macbeth-Evans, American

The analysis of these glasses gave the following results:

Make of Glass	SiO_2	As_2O_3	Sb_2O_3	Al_2O_3	ZnO	CaO	MgO	K_2O
A	64.58	....	....	6.28	11.78	0.08	0.12	trace
B	64.39	....	....	4.07	none	7.38	0.10	4.02
C	65.45	....	....	6.18	9.06	0.40	trace	0.34
D	66.51	....	....	6.74	3.62	4.35	0.33	2.58
E	66.38	....	....	6.60	8.66	0.49	0.12	1.09
F	64.35	....	....	9.84	none	6.58	0.22	1.59
G	69.40	....	....	1.00	7.35	5.78	trace	5.92
H	72.03	....	....	0.90	none	7.93	0.52	0.73
I	71.82	....	....	1.12	3.07	5.20	0.16	1.47
J	73.67	....	....	0.36	none	7.50	trace	3.50
K	74.32	none	none	2.35	none	3.67	0.11	1.38
L	68.03	none	0.45	2.62	7.39	0.80	3.41	0.30
M	69.84	none	1.00	0.96	3.80	1.69	6.25	0.70
N	68.58	0.18	none	2.90	3.60	2.05	2.53	1.29
O	80.62	0.66	none	2.00	none	0.22	0.29	0.61
P	66.62	none	1.80	3.11	8.20	0.20	3.29	1.40
Q	66.80	2.05	1.29	2.54	9.75	1.73	2.60	1.75
R	75.00	trace	none	0.24	none	8.73	0.15	7.84
S	76.10	none	none	0.20	none	6.30	0.29	5.60
T	67.42	none	0.65	0.65	8.12	3.14	4.50	3.06
U	76.20	none	0.30	0.30	none	8.97	trace	7.62
V	71.03	0.05	0.45	1.57	5.30	0.64	2.61	0.30

Make of Glass	Na_2O	B_2O_3	MnO	Fe_2O_3
A	7.38	10.03	trace	0.10
B	13.42	1.93	....	....
C	11.81	7.13	none	0.09
D	11.52	4.57	0.10	0.08
E	10.02	6.90	trace	0.12
F	9.90	7.60	trace	0.10
G	6.46	4.01	0.08	0.12
H	17.62	none	trace	0.10
I	15.08	2.08	trace	0.16
J	13.06	1.73	0.10	0.04
K	17.56	none	0.10	0.14
L	11.18	5.81	trace	0.20
M	11.25	4.02	trace	0.34
N	10.01	8.0	trace	0.20
O	3.83	11.90	trace	0.16
P	11.76	3.74	0.13	0.14
Q	7.40	4.13	trace	0.17
R	7.29	none	trace	0.10
S	11.16	none	0.10	0.14
T	9.92	2.35	trace	0.21
U	7.07	none	trace	0.14
V	10.74	7.44	trace	0.35

These glasses when classed according to their resistance to attack, the best first, fall in the order shown in the following table; those classed as "good" showed losses falling within the limits: boiling water, total loss 0.5-1.4 mg.; water at 183°, total loss 15.4-85.9; 20 per cent HCl, boiling, loss 0.7-9.7 mg. per sq. dm. of surface exposed.

GRADING OF LABORATORY GLASSWARE ACCORDING TO ITS RESISTANCE TO ATTACK

Grade	Water at 100°	Water at 183°	Boiling 20% HCl
Good	V	O	S
	S	F	O
	—	E	V
	A	B	R
	G	G	P
	C	C	M
	O	A	L
	—	D	N
	L	L	T
	F	V	Q
	—	N	G
	E	Q	J
	N	P	I
	—	—	D
	P	—	H
	B	—	E
	M	—	C
	Q	—	—
	D	—	—
	T	—	—
Moderate	I	T	B
	R	M	—
	U	—	—
Bad	K	K	F
	J	I	A
	H	J	—
	—	H	—
	—	S	—

Of the glasses tested seven fall in the "good" class in every test (see chapter on alkalies for tests with alkaline substances), of which three are of British manufacture, two American and two German. The authors conclude that 1. zinc-aluminum or aluminum boro-silicates are most relied on at present, the former being the most popular; on the whole the best glasses are of this type; 2. lime-soda glasses are as a rule not very resistant to water nor to sodium carbonate, are moderately resistant towards dilute alkali, excellent towards strong alkali, and the best type for use with acids; 3. silica gives resistance towards water and acids but not towards caustic and carbonated alkalies; 4. boric oxide in a molecular ratio to silica of about 12 : 100 increases the resistance to water but lessens that to alkali and hydrochloric acid; 5. lime is not of advantage for resistance to water, and is a disadvantage for use with sodium carbonate, but increases the resistance to strong caustic and hydrochloric acid; 6. large proportions of alkalies are to be avoided, since they decrease the resistance to water, acid and alkali.

Fused Silica.

Fused silica ware, SiO_2, is an expensive substitute for glass in the laboratory, but is unsurpassed for many purposes because of its practically complete resistance to attack by water and all acids except hydrofluoric at ordinary temperatures, and because of its extremely low coefficient of expansion which allows it to undergo the most extreme and sudden temperature changes without cracking; for example the silica tube of a laboratory combustion furnace may be cooled for part of its length by mopping with wet asbestos without danger. Practically all forms of laboratory apparatus that are found in glass are duplicated in silica, both glazed and unglazed, transparent and cloudy. In addition to laboratory apparatus, factory sized units are made in considerable variety—evaporating dishes, concentrating pans, pipes, funnels, stills, etc.

Besides hydrofluoric acid phosphoric acid attacks silica high temperatures, the attack beginning at 500°,[13] and water begins slowly to gelatinize fused silica at 400° and quartz crystals at 500°.[14]

The action of hydrofluoric acid on silica shown by the equation

$$4HF + SiO_2 \longrightarrow SiF_4 + 2H_2O$$

takes place at room temperature and is made complete by warming, silicon tetrafluoride being driven off as a gas.

Fused silica begins to lose its mechanical strength on being heated to 1100°.

Enamels.

Enamels and vitreous glazes are closely related to glass in their uses and chemical behavior. Glass enameled metal has two important uses; first, in the manufacture of domestic cooking utensils, second in the manufacture of industrial chemical apparatus.

The chief requisites in enameled cooking ware are mechanical strength (resistance to shock, wear and temperature changes) and insolubility of any part of it in dilute acid solutions, for nearly all food preparations are neutral or faintly acid in reaction. Enamels which yield soluble lead or other toxic salts to acids are obviously dangerous. The tests usually applied to enameled ware consist in boiling dilute acetic acid in the vessel to be tested and determining its loss of weight or the kind and weight of material dissolved or both. In tests of ware of American manufacture in which 500 c.c. 4 per cent acetic acid were boiled in each vessel for ½ hour white and gray enamel stood up better than blue.

The white and gray enamels were entirely unaffected by 1 and 2 per cent acid; only 2 of twenty-three makes yielded soluble lead. When 200 c.c. 4 per cent acetic acid were heated in the samples for 6 hours on the steam bath, the losses in weight varied from 0.05-0.08 g. in ware of proved good quality through 0.2-0.5 g. in ware of medium quality to 0.6-1.2 g. in inferior grades.[15]

In a study of the relative resistance of enamels to different acids 2 g. finely ground frit (50-100 mesh, 4.9 per cent; 100-200 mesh, 33.9 per cent; finer than 200 mesh, 61.2 per cent) were weighed into a 400 c.c. beaker and let stand 24 hours at room temperature after thorough stirring up with 100 c.c. of the acid used. The loss in weight of the frit was determined. The results are shown in the following table:[16]

LOSS OF WEIGHT OF ENAMEL FRITS IN ACIDS

Kind of Acid	Maximum Strength Tested	Per Cent Acid Causing Greatest Loss	Amount of Greatest Loss
Acetic	94%	20%	0.03 g.
Nitric	70	12	0.12
Sulfuric	96	8	0.16
Hydrochloric	37	10	0.19

The solubility of the lead of enamels in acetic acid is affected by the silica content of the enamel but does not vary continuously with it. The solubility decreases with increasing silica content up to a ratio of 2.5 mols SiO_2 : 1 mol PbO, and then increases. If part of the lead is replaced by sodium, potassium, calcium, barium, magnesium or zinc, less lead is dissolved, and the presence of aluminum still further decreases its solubility.

Wood.

Wood, of the organic materials considered here, is the most used and most useful because of its cheapness, strength, ease of manipulation and its resistance to the action of many chemicals that vigorously attack metals.

The kinds of wood commonly met with in this country and the approximate order of their popularity for chemical work in general are:[17]

1. Red Gulf or Louisiana cypress (*Taxodium distichum*)
2. Long leaf, yellow or hard pine (*Pinus palustris*)
3. California redwood (*Sequoia sempervirens*)
4. White pine (*Pinus strobus*)
5. Douglas, Washington or Oregon fir (*Pseudotsuga taxifolia*)
6. Hard maple (*Acer saccharum*)
7. Yellow poplar (*Populus deltoides*)
8. White oak (*Quercus alba*)
9. Tamarack (*Larix laricina*)

10. Spruce (*Picea rubra*)
11. Norway pine (*Pinus resinosa*)

The results of some recent experimental work on the behavior of wood towards various chemical reagents have been published in two articles which fill a long felt want, for hitherto there has been practically no systematic information covering this field available in the literature.[17, 17a]

All woods when first used impart more or less color to solutions and other liquids which they contain; oak and redwood especially impart color to water hot or cold; maple is better in this respect, and fir, pine and cypress follow in the order named. The effect of aqueous solutions of acids and acidic salts on six woods is shown in the following table on a scale of 4, 1 indicating little or no color extracted by the solution, and 4 indicating strong color extraction.

RELATIVE EXTRACTION OF COLORING MATTER FROM WOODS BY ACID SOLUTIONS[17]

Solution	Cypress	Long Leaf Pine	Douglas Fir	Red-wood	Hard Maple	White Oak
5% and 25% acetic acid..	1	1	1	2	1	2
50% and 100% " " .	2	2	2	3	2	3
5% and 25% HCl........	1	1	1	2	1	2
Concentrated "	4	4	4	4	4	4
10% H_2SO_4	1	1	1	3	1	3
25% "	2	2	1	3	2	3
5% HNO_3	4	4	4	4	4	4
10% $NaHSO_3$	2	2	2	2	2	4
10% NaCl	2	1	1	2	2	2
10% $CaCl_2$	1	1	1	2	1	2
25% "	1	1	1	2	2	2

The absorption by wood of the same chemicals was studied and the results summarized and expressed in the same terms as were used in the previous table; since no simple relation between the concentration of the solutions used and the amount absorbed was apparent, the results obtained with several concentrations of each solute were averaged in making the following table. High absorption is indicated by 4, low by 1.

RELATIVE ABSORPTION OF ACID SOLUTIONS BY WOOD[17]

Solution	Cypress		Douglas Fir		Long Leaf Pine		Red-wood		Hard Maple		White Oak	
	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold
Water	3	2	4	3	3	3	4	3	4	4	4	4
HCl	4	2	4	3	3	2	4	3	4	4	4	3
H_2SO_4	4	2	4	2	3	3	4	3	4	4	4	3
HNO_3	2	2	3	3	3	2	3	3	4	4	4	4
Acetic acid..	3	3	2	2	2	2	3	3	4	4	3	3
$NaHSO_3$ ...	3	3	3	3	2	2	4	4	4	4	3	3
NaCl	3	1	4	2	3	1	4	3	4	3	3	2
$CaCl_2$	1	1	2	2	1	1	3	3	3	3	1	1

Data for various concentrations of sulfuric acid are given in Fig. 13,[17a] and in Fig. 14 are found average values for a number of chemicals.[17a]

All woods expand in aqueous solution, and part of this expansion is lost on subsequent drying. Redwood shows the greatest swelling and oak the least. The change in dimensions (contraction or expansion) resulting when wood is immersed in a solution may be termed temporary contraction or expansion; that change which persists after the wood has dried out may be considered permanent. Temporary expansion in various strengths of sulfuric acid is shown in Fig. 15, and in Fig. 16 and Fig. 17 are given the permanent changes in a variety of solutions.[17a]

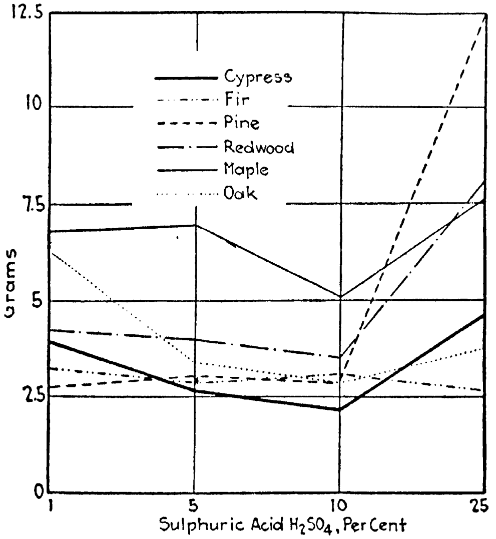

Fig. 13.—Absorption of H_2SO_4 by Wood.

Nitric acid is probably hardest on wood; this acid, mixed acid (nitric and sulfuric), or nitrous fumes and spray quickly destroy any wood, first turning it a deep yellow and then transforming it to a gelatinous, partly fibrous pulp. Sulfuric acid, if concentrated, carbonizes wood. The non-oxidizing acids may be handled in wood, but if the acids are strong, the wood is slowly hydrolyzed and destroyed. From this it follows that the strong mineral acids, like hydrochloric and sulfuric acids, can be handled in wooden apparatus only at very much lower concentrations than the weaker organic acids, but concentrated hydrochloric and phosphoric acids may be shipped in wooden containers that have

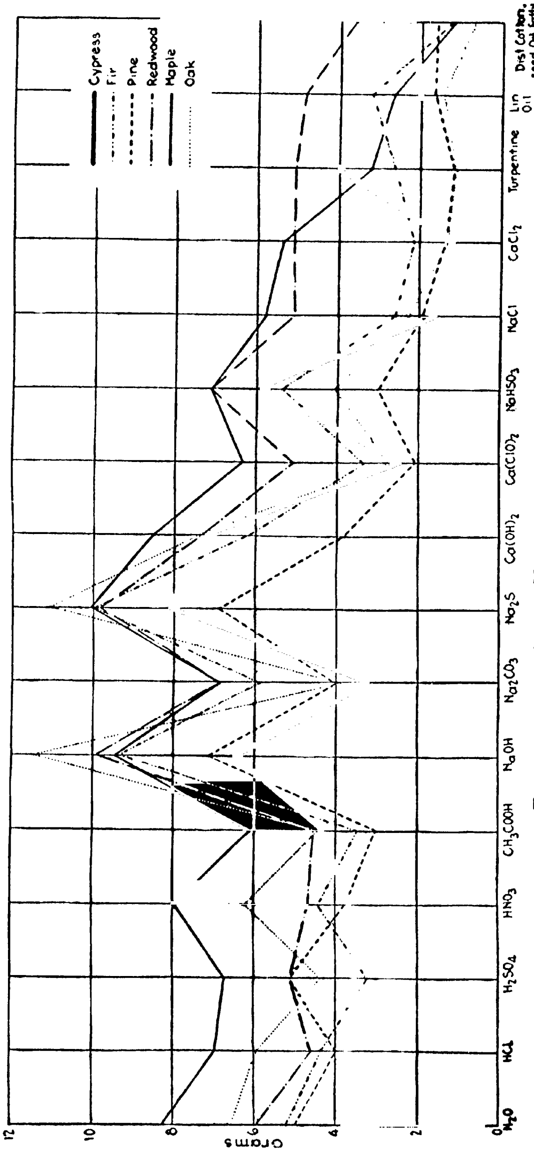

FIG. 14.—Absorption of Various Solutions by Wood.

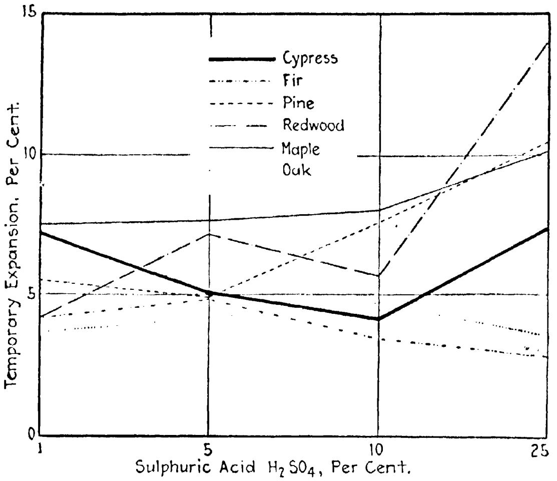

Fig. 15.—Expansion in H_2SO_4 at Different Concentrations.

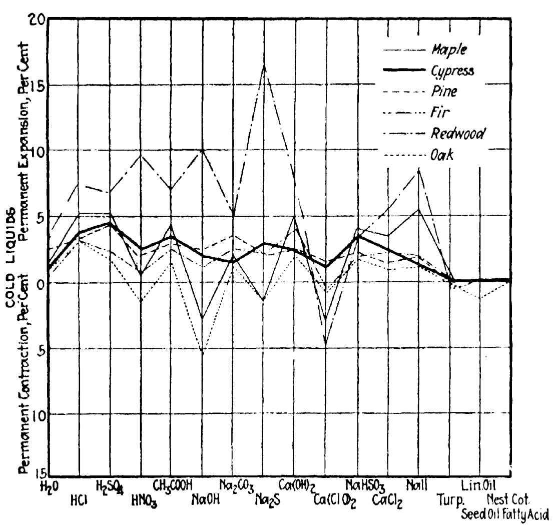

Fig. 16.—Expansion or Contraction of Wood in Various Cold Solutions.

been treated with paraffine or water glass or given some similar protective coating.

Data on the effect of some of these chemicals on the physical condition of the six woods may be summarized as in the table that follows. A minus sign indicates no appreciable action; a plus sign, brittling, softening or shrinking; two plus signs, de-

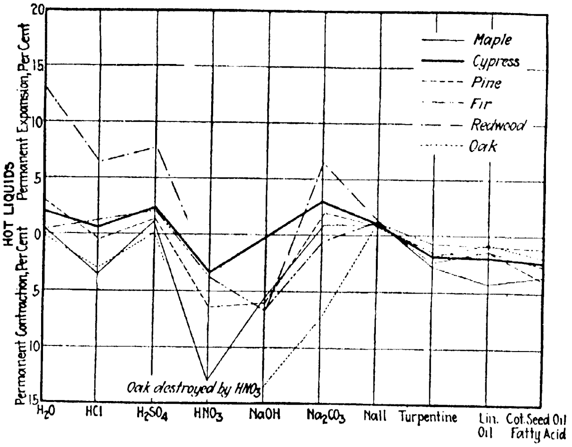

FIG. 17.—Expansion or Contraction of Wood in Hot Solutions.

struction of the wood. Signs enclosed in parentheses indicate inferences from the authors' statements, while the others are based on direct statements.

EFFECT OF ACID SOLUTIONS ON PHYSICAL PROPERTIES OF WOOD[17]

Solution	Cypress	Douglas Fir	Long Leaf Pine	Red-wood	Hard Maple	White Oak
Acetic acid 0-100%....	—	—	—	—	—	—
5% HCl cold.........	(—)	(—)	(—)	+	(—)	(—)
25% " "	—	—	—	(+)	+	+
Conc. " "	++	++	++	++	++	++
5% H_2SO_4 cold........	—	—	—	+	—	—
25% " "	—	(+)	—	(+)	(+)	(+)
" " hot	++	++	++	++	++	++
Conc. " cold	++	++	++	++	++	++
5% HNO_3 "	—	—	—	(+)	(+)	(+)
" " hot	+	+	+	+	+	+
NaCl "	(—)	(—)	(—)	+	(—)	(—)

At least one wood is suitable for each of the chemicals in moderate concentration except nitric acid. Cypress, fir and pine are the woods least affected, while maple and oak are of more restricted usefulness. Maple withstands 10 per cent hydrogen peroxide indefinitely.

The results of a somewhat more detailed test with hydrochloric, sulfuric and nitric acids are shown in the next table.[13a] In the notation used

S	indicates	any softening effect
W	"	warping, cracking, distortion or the like
Shd	"	shredding
Ch	"	charring

and a blank indicates no test.

Hot solutions of ammonium nitrate wear out wooden tanks rapidly either by depositing crystals in the interstices of the wood where the solution has permeated, or by crystallizing out in the seams between the staves.[18]

A census of the opinions of users of wood in chemical plants, compiled by the Forest Products Laboratory and referred to in the article from which the above data were taken, resulted in the following generalizations:

"For pickling tanks cypress was the most popular with white pine a close second. The other resinous pines were also used.

"For hydrochloric acid any variety of resinous wood, if impregnated with tar or other protective coating, was apparently suitable.

"For acetic acid any wood was satisfactory, with the possible exception of Douglas fir.

"Cypress was preferred for saponifications and for most acid work, while long leaf pine was also very popular.

"Filter press plates are usually made of paraffined maple, although other woods are sometimes used.

"Tamarack is suitable for hydrofluosilicic acid up to 12 per cent, and for dilute organic acids."

Protective Coatings for Wood.

Hauser and Bahlman conclude their article with a discussion of protective coatings as follows:[17a]

Waxes or gums, asphalts and coal-tar pitches are sometimes employed as a protective coating upon woods which are to be exposed to the action of corrosive liquids. These products may be either liquids or solids at normal temperatures. The liquids, usually called acid-proof paints, are applied with a brush, whereas the solids are melted and then applied. In the latter case, usually a prime coat of the same or similar material in liquid form is first applied to act as a binder. With those solids which have low melting points or no fixed melting point, as in the case of coal-tar pitch, some substance is frequently mixed with the protective material or else duck or burlap properly secured to the tank and placed between coatings of the pitch, etc., is used to prevent the material from running down the vertical sides of the tank. Whether these preparations are successful in preventing the penetration of a liquid will depend upon the resistance of the coating to the action of the chemical and upon the completeness with which the pores of the wood are covered. Various coal-tar and asphaltic paints as well as solid materials were tested to determine

EFFECT OF SOLUTIONS ON THE PHYSICAL NATURE OF WOOD (Hauser and Bahlman)[17a]

		Cypress		Fir		Pine		Redwood		Maple		Oak	
		Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot
HCl (Hydrochloric Acid), per cent.	5	.....	.....	.....	S	.....	.....	W	S, W	.....	.....	.....	.....
	10	.....	.....	.....	S	.....	.....	W	S, W	.....	S	.....	.....
	25	.....	S, W	.....	S, W	.....	S	W	S, W	S, W	S, W	W	S, W
	50	S, W	.....	S, W	.....	.....	.....	S, W	.....	S, W	.....	S, W	.....
	conc.	S, W	.....	S, W	.....	S, W	.....	S, W	.....	S, W, Ch	.....	S, W	.....
H_2SO_4 (Sulphuric Acid), per cent..	1	.....	S	.....	S	.....	.....	W	S	.....	.....	.....	W
	5	.....	S	.....	S	.....	.....	S, W	S, W	.....	S	.....	.....
	10	.....	S, W	S	S	.....	.....	S, W	S, W	W	S	W	.....
	25	W	S, W	S, W	S, W	.....	S, W	S, W	S, W, Ch	S, W	S, W	S, W	S, W
HNO_3 (Nitric Acid), per cent......	5	.....	S	.....	S	.....	S, Shd	S, W	S, W	.....	S, Shd	.....	S, W, Shd
	10	.....	S, Shd	.....	S, Shd	.....	S, Shd	S, W	S, W, Shd	W	S, Shd	S, W, Shd	S, W, Shd
	25	S, W	S, Shd	S, W	S, Shd	S, W	S, Shd	S, W	S, W, Shd	S, W, Shd	S, Shd	S, W, Shd	S, W, Shd

their resistivity to the various chemical solutions. Melting point determinations were also made on the solid materials.

Most of the samples tested showed great resistivity to the various chemicals used but in the case of strips covered with liquid preparations, absorption took place, expansion or contraction occurred and the other physical manifestations were evident, although much retarded. It would seem that although the material itself was unacted upon, the chemical solution would get through the thin protective film and attack the wood. With the solid materials, especially when the wood was thoroughly and heavily coated, the penetration was very much reduced and thus very much better production was afforded.

Cotton

Cotton is the most used of the textile materials for industrial purposes, and it is especially used in chemical plants for filter cloths, bags, etc. Chemically the cotton fiber consists of relatively pure cellulose, the formula of which is $(C_6H_{10}O_5)_x$; the x subscript indicates that its molecular weight is unknown.

From an engineering point of view the most interesting chemical characteristics of cotton are its relative sensitiveness to acids and inertness towards alkalies, being in these respect the inverse of the animal fibers wool and silk. The destructive action of acids is due to a number of reactions of the types of hydrolyses, hydrations, dehydrations, esterifications, etc., not thoroughly understood in many cases, and too complicated to go into at length here. There is one difference that must be taken into account in practical work between the volatile and non-volatile acids. While the action of all of them is more or less destructive on cotton, action continued for a short while may be negligible; if therefore cotton moistened with a volatile acid solution is allowed to dry, the acid will evaporate with the water and its action cease; with a non-volatile acid, on the other hand, as the water evaporates, the acid solution on the fiber becomes more concentrated, and the destructive action continues until the acid is exhausted.

Sulfuric acid when concentrated dissolves cotton to a viscous solution from which the addition of water precipitates the amorphous starch-like substance amyloid, $(C_{12}H_{22}O_{11})_x$. Dilute sulfuric acid, like other dilute acids, hydrolyzes cotton to dextrine and glucose. Concentrated hydrochloric acid dissolves cotton. Hydrofluoric acid when dilute has a peculiar effect, transforming cotton into a tough, transparent, flexible waterproof material. Concentrated nitric acid alone oxidizes cotton to oxalic acid among other products, but if the nitric is mixed with concentrated sulfuric acid, so-called nitro-cottons are produced. These are really nitrates or nitric acid esters of cellulose (among them is gun cotton) which have quite different chemical characteristics from cotton.[20]

Advantage may be taken of this change in characteristics to prepare filters resistant to strong acids.[21] Ordinary dry cotton filter cloths are stretched loosely on aluminum frames and immersed for one hour in cold 80-85 per cent nitric acid and then for twenty minutes in 93 per cent sulfuric acid, after which they are washed thoroughly and dried, care being taken to remove all the free acid in the washing. Such filters are not very strong mechanically and should be well supported in use, but they stand 60 per cent sulfuric acid even at 100°. On the other hand they are at once destroyed by solutions of iron salts.

Some salt solutions have a tendering effect on cotton, in most cases because of their acid reaction. Zinc chloride however has a specific action, and concentrated solutions dissolve the fiber, double zinc compounds being formed under certain conditions. If one part of cotton is warmed at 60-80° in a solution of 4-6 parts $ZnCl_2$ (anhydrous) in 6-10 parts water, it will gelatinize, and if it is further heated at 95-100°, it will dissolve. Solutions of zinc chloride in concentrated hydrochloric acid will dissolve cotton cold.

The minimum strengths of sulfuric and hydrochloric acids that will tender cotton were determined under two different sets of conditions: a. the cotton was boiled in the acid solution one hour; b. the cotton was immersed in the acid and when thoroughly wet, was wrung out and heated at 120° for ten minutes. The results showed that much weaker hydrochloric than sulfuric acid would tender the fiber. The minimum strengths found were:[22]

Experiment	HCl	H_2SO_4
a	1/128%	1/32%
b	1/400	1/128

Apparently after the cotton fiber has been tendered by the action of sulfuric acid, dried on the fiber without heat, a certain return of strength occurs when the acid in the fiber is neutralized. Tensile strength tests indicate that: 1. the tendering action increases the longer the acid remains on the fiber; 2. the cotton gains in strength on washing out the acid, the gain being least in fibers tendered most; 3. neutralization by steeping in dilute alkali gave results indistinguishable from those obtained when the acid was washed out. In the tests 2/20's cotton yarn was used and 0.5 N, 1 N and 2 N sulfuric acid.[23]

A study has been made of the tendering effect on cotton fiber of a number of organic acids both alone and mixed with Glauber's salt. In some cases the solutions were dried on the fiber and the fiber steamed, and in others the steaming was omitted. The extent of the decomposition was determined by measuring the reducing power on an alkaline copper solution of the decomposition products (Schwalbe's method modified);[24] the greater the decomposition of the cotton, the greater the reducing power.[25] The results of the tests were as follows:

ACTION OF ORGANIC ACIDS AND GLAUBER'S SALT ON COTTON

Acid	Concentration	Treatment	Copper Value
Tartaric	5 g./100 c.c.	Dried, steamed	4.8
"	Same + 1.6 g. Glauber's salt	" "	2.82
"	Same + 20 g. Glauber's salt	" "	Very slight, no tendering
Citric	5 g./100 c.c. + 20 g. Glauber's salt	" "	Same
Oxalic	5 g./100 c.c.	" "	5.75
Citric	" "	" "	2.63
Formic	....	" "	No action
Acetic	....	" "	" "
Oxalic Tartaric Citric Formic Acetic	....	Dried only	No action

In every case where Glauber's salt was added the destructive action was less than when the salt was absent. This has been questioned by other workers, and, if the experimental results are to be relied upon, the effect of the addition of salts, depends on the kind and concentration of the acid. For example[26] cotton was boiled under a reflux condenser with acid solutions and its tensile strength determined after this treatment.

Solution	Tensile Strength
Water	11.06
2 per cent oxalic acid	6.71
2 per cent oxalic acid + 20 per cent Glauber's salt	9.84

Sodium chloride and hydrochloric acid tender cotton less than hydrochloric acid alone, probably because of the lessening of the concentration of the hydrogen ion by the large amount of chloride ion present.

Wool.

Wool, being, as has already been mentioned, the inverse of cotton in its resistance to reagents, is scarcely attacked by strengths of acid that entirely destroy the cotton fiber, but is on the other hand destroyed by quite dilute alkalies. Chemically wool is chiefly keratin, a basic, nitrogenous material that is the chief constituent of the hair and horns and one of the constituents of the skin of mammals, and its chemical behavior is very like that of other animal fibers, even so different a fiber physiologically as silk. The average composition of wool keratin is[20]

	Per Cent
C	50
H	7
O	26–22
N	15 ·17
S	2–4

Wool readily absorbs a certain amount of acid when treated with a dilute solution, and if it is afterwards boiled with successive portions of water till the last is neutral, not all the acid absorbed will have been removed. Dilute acids do not affect wool, with the exception of nitrous acid, which diazotizes it, and nitric acid, which colors it yellow. If the concentration of the nitric acid is less than 4 per cent, the coloration is not very marked.

Concentrated strong acids, however, completely destroy the fiber if the action is allowed to continue for any length of time. If wool is immersed in cold concentrated sulfuric acid for a short time only, its strength is not seriously affected, but it is changed chemically, having a greater affinity for basic dyes and none for acid dyes.[27] At high temperatures the action of the strong acids is, of course, more vigorous, and long continued boiling even with water decomposes it to some extent. At 130° water changes the fiber to a substance that when dry is a powder, and at higher temperatures dissolves it.

Because of its acid resistant qualities woolen cloth has a large use in chemical plants as a filtering medium for dilute acid solutions. In picric acid plants woolen Albany cloth was used for filtering picric acid from spent nitrating acid of an average composition of 45 per cent sulfuric, 3 per cent nitric and 0.5 per cent picric acid. The deterioration was somewhat rapid under these severe conditions, but the cloth stood up sufficiently well to offer a practical solution of the filtration problem.[28]

Silk.

Silk, like wool, is protein in nature, but differs from the latter in containing no sulfur; its chief constituent is the protein fibroin, the average analysis of which is given as: [31]

	Per Cent
C	48.3
H	6.5
N	19.2
O	26.0

Furthermore it is in general similar to wool in its behavior towards acids and alkalies, as has already been mentioned, being resistant to the former and sensitive to the latter; in some details, however, it differs from wool. Like wool it combines with dilute acids and is dissolved by concentrated alkalies, but it is not as sensitive to alkalies as wool is, and ammonium hydroxide has no effect on it.

Concentrated sulfuric acid acting for only a few minutes causes a 30-50 per cent contraction of the fiber without any other damage than a loss of luster, but long continued action dissolves the silk.

Hydrochloric acid of specific gravity 1.145 (28.6 per cent) causes a one-third contraction of the fiber. Below this strength this effect disappears, and above specific gravity 1.15 (29.6 per cent) the acid causes complete disintegration. This shrinking action is used for creping, and the action is complete in from one to two minutes.[29] Nitric and sulfuric acids may be used in the same way.[30]

Ordinary strong nitric acid of specific gravity 1.33 (52.4 per cent) acting for one minute at 45° gives silk a yellow color fast to light and washing, but pure nitric acid, free from nitrous acid and oxides of nitrogen, is without this effect (cf. action of nitric acid on metals p. 59). Alkalies deepen the color of this nitro silk, and concentrated sulfuric acid converts it to a gelatinous mass.

Hot glacial acetic acid dissolves silk.

Neither fluosilicic nor hydrofluoric acid (cold, 5 per cent) harms silk; they may therefore be used for removing inorganic salts.

Solutions of some salts have a pronounced effect on silk. A 0.5 per cent solution of sodium chloride completely destroyed the fiber in 12 months, a 1 per cent solution produced pronounced tendering in 2 months, and 2-5 per cent solutions caused noticeable tendering in 7 days. Other chlorides have a similar but less pronounced effect. Alkaline zinc chloride, ammoniacal copper and nickel and strong stannic chloride (of specific gravity, 1.35, 48 per cent) solutions dissolve silk, and the latter three may be used for its analytical separation from cotton. An alkaline solution of copper sulfate in glycerine may be used for the same purpose (16 g. $CuSO_4 . 5H_2O$ are dissolved in 10 g. glycerine and 150 c.c. water, and a $NaOH$ solution is added until the precipitate first formed is redissolved).

Hair Cloth.

Hair cloth made of camel and other hair is extensively used as a filtering medium for acid liquors.[7]

The following is an abstract of a recent investigation of hair cloth by F. R. McGowan and C. W. Schoffstal of the U. S. Bureau of Standards.[31]"

Press cloth is a heavy textile fabric made from various kinds of combinations or textile fibers, generally hair fibers. This cloth ranges up to one-half inch in thickness and is usually made 13 inches in width. Because of its great strength and porosity it is used to advantage principally in the presses of the oil-pressing industries.

The use to which this press-cloth material is put requires that the cloth have great strength and resiliency. This latter factor has made it desirable to use hair fibers to a large extent. Of these hairs camel hair seems to be used most, and human, horse, goat, mohair, and other hairs have been adopted with varying degrees of length and satisfaction of service. There is also some wool press cloth in use.

Previous to the war approximately 90 per cent of the camel's hair used by American press-cloth manufacturers was of the average grade of Russian camel hair and the remainder of Chinese camel hair. The war, however, prevented the importation of the Russian product and forced the American manufacturers of camel's-hair press cloth to use the Chinese grade. Human hair is imported principally from China and Italy. Horse hair is a substitute for human hair, but is used in very limited quantities. Since it has not proved entirely satisfactory, goat hair is used in large quantities in the manufacture of the so-called gray wool press cloth, which contains 10 to 50 per cent of goat hair.

It is the experience of several of the larger cottonseed oil companies that it takes half a pound of press cloth for each ton of cotton seed worked. The amount varies with the different mills, some using more, some less, but half a pound may be considered a fair estimate.

The ultimate cost of press cloth has always been of vital interest to millmen, and there is a vast range of price between the greatest and least cost. This variation results from a number of causes improper handling, storage and cleaning of seeds, improper linting, separation, crushing, cooking, forming, or pressing of the meal all influence the wear and tear on the cloth.

It is a well-known fact that all textile material is influenced in its properties by atmospheric moisture. The effect of the moisture on the weight is of interest in this connection. Various other textile branches have taken up the problem of moisture content in relation to weight. The silk industry, owing to the high cost per pound of its product, has formed a very comprehensive system of transacting sales on a standard moisture basis. It has been found very advantageous in this instance to set a standard moisture content and to buy on that basis. It is recognized that the material always contains some moisture under ordinary conditions, so that in transactions on a weight basis it was considered desirable to agree upon some standard moisture condition and to allow the percentage of moisture which was contained in the material at that condition. The silk interests are not alone in following out such a project, for definite standards have been fixed and adhered to more or less for transactions in wool, cotton, and various other fibers. It is true that this condition seems to be more prevalent in Europe than in the United States, and for that reason indications point to the fact that the American textile interests are somewhat negligent in not giving this factor more consideration. The United States Government in its specifications has taken cognizance of the influence of moisture on properties of cloth, and it is hoped that the textile trade also will soon come to do so.

The question of moisture content in its relation to selling is quite frequently misunderstood. In earlier days in the textile trade unscrupulous dealers, recognizing the ability of textile fibers to absorb moisture, took advantage of this by sprinkling or adding moisture in some way before the material was weighed. This practice fortunately has lessened, but there still remains the natural increase or decrease in weight due to changes in the humidity conditions of the atmosphere which are involved in transactions made where this atmospheric moisture is disregarded. Much of the opposition to moisture determinations developed from the fact that tests of this nature bring to buyers and sellers visions of large and expensive humidity regulating devices at their plants with the resulting additional expense. Moisture determinations would not involve more than the slight additional trouble of packing and sending the sample to some easily accessible laboratory for tests for moisture content. Some press-cloth manufacturers also look upon this as an infringement on their methods of manufacturing, but here again it can be stated that the manufacturer might pass his material through any series of wet processes and all the requirements would be met by adjusting the selling weight to that moisture content which would be permitted under normal conditions.

The percentage of oil content, while mostly a manufacturing problem, is also of primary importance to the buyer of press cloth. Hair fibers similar to wool, in their natural state, contain oil excreted at the roots of the hair fibers, and this often mixes with the perspiration and dirt to form a coating over the fiber. In the wool industry this is entirely removed by scouring to improve the feel and appearance of the fibers, to permit more efficient manufacturing processes, and to enable the fiber to take the dye. Some press-cloth fibers also have been scoured, but the expediency of scouring is open to question as to whether the additional expense caused by shrinkage in weight and labor involved is counterbalanced by the better qualities of the press-cloth material. It must also be considered that the removal of all the natural oil causes the fibers to lack adhesiveness and increases waste or flyings. It is necessary then to add a certain amount of oil before the carding process. This is later removed in the case of wool manufacturing, so that the finished product is free from oil. In the case of hair press cloth, however, we find either the natural oil plus some of the additional oil or, if the fiber were previously scoured, this added oil alone remains. This condition involves a point of argument.

From the manufacturer's standpoint it is admittedly necessary to add oil to permit efficient manufacturing. On the other hand it is inadvisable because of the additional expense involved in scouring the finished press cloth. Each manufacturer has different ideas as to what kind of oil to use, if any, and how much is needed.

According to the user's views, however, this oil is unnecessary in the work in which the press cloth is used, since the fabric is working with oil. He points out that since the oil is not essential in his work, and since press cloth is bought by weight, his interest demands that the amount of oil put into the fabric be minimized to eliminate the buying at press-cloth prices of a material which is of no value. As this oil is not actually detrimental except in extremely isolated cases, it would seem advantageous to ascertain and deduct from the gross weight the average percentage of oil in a shipment rather than to run the cloth through the scouring process. Rather than deduct the entire oil content it has been suggested that a certain permissible percentage of oil be fixed as standard which will allow the manufacturer to add such oil as is necessary for proper manufacturing and permit any excess to be subtracted from the weight of the shipment. It was for the purpose of having this oil standard as well as moisture content standard fixed satisfactorily for manufacturer and user alike that this matter was brought to the attention of the U. S. Bureau of Standards by one of the largest users of this material.

In a preliminary study of this problem a search through the various sources of information revealed very little data or information that would aid in its solution. It was found that various oil-pressing mills were testing or having tested, with varying results, samples of the cloths which were purchased. It was noted that several methods of tests were in vogue, and this led to confusion. Moisture content was determined as received at the testing house, and there was no attempt to have the test samples delivered in moisture-tight packages, so as to prevent changes in moisture condition between the weighing room and the test room. Determinations of moisture content, to be of any value whatever, should show the percentage of moisture present at the time of the weighing on which payment is based. The oil content with the exception of any slight evaporation would remain the same, so that the standardization of methods of determination would be all that is necessary to afford uniform results.

Cocoanut Fiber.

Cocoanut fiber is fairly resistant to dilute acids, and mats of this material may be used for filtering weakly acid solutions, e. g., on the perforated false bottom of a tank. For example, at the Chuquecomata mine in Chile copper ore is leached with 12 per cent sulfuric acid in concrete leaching vats lined with mastic asphalt, and filtered through cocoanut matting laid between wooden planks.[32]

Rubber.

Rubber, one of the most important manufactured organic materials, is chiefly used because of its unique physical properties, but its chemical inertness makes it very valuable for special purposes in chemical apparatus. Tanks, pipes, centrifugal baskets, etc., are lined with both hard and soft rubber, not because of its physical as much as because of its chemical characteristics.

Several manufacturers [33] have successfully applied soft rubber linings to all forms of cast iron, wrought iron and steel apparatus ranging from standard flanged pipe through kettles and miscellaneous apparatus to cylindrical tanks up to six feet in diameter by fifteen feet long. The coating cannot be successfully applied to brass or copper. Such apparatus will withstand the following maximum strengths of acids and acidic substances:

	Per Cent
Hydrochloric acid	38
Sulfuric "	70
Chromic "	10
Acetic "	10
Ferrous chloride	50

and any strength of the following:

Oxalic acid and oxalates
Tartaric acid and tartrates
Phosphoric acid and phosphates
Sodium chloride

as well as any other approximately neutral salts. The lining is, however, readily attacked by oxides of nitrogen and free halogens. The lining can in some cases be used at temperatures as high as 130° C.

For storing cold hydrochloric acid tanks have been successfully used that were lined with a layer of canvas cemented to the wall of the tank, the inner surface of the canvas being then painted with one or more coats of a solution of pure gum rubber in one of the usual rubber solvents. After this had thoroughly dried, the tank was used without further treatment.

Hard rubber is used, like soft rubber, for lining metal apparatus, but its brittleness is a disadvantage. Unlike soft rubber, however, it can itself be used for some kinds of apparatus such as stop-cocks, pumps, etc., without the necessity of a metallic or other backing. It is resistant to dilute acids, but attacked by strong concentrated acids and strong oxidizing agents.

Hydrofluoric acid, because of its corrosive action on almost all engineering materials, including glass and all siliceous materials, is difficult to handle in both the plant and laboratory. Lead offers some resistance, but hard rubber equipment is now manufactured which the makers claim is far superior to lead in its resistance to corrosion; the articles manufactured include pumps, pipe connections, tanks, etc.[34]

For handling hydrofluoric acid in the laboratory transparent Bakelite graduates and pipettes have been used successfully; they are unattacked by 48 per cent hydrofluoric acid.[35]

For smaller pieces of apparatus both hard and soft rubber are used, the former where rigidity, the latter where flexibility is required, as in hose pipe. Special grades must be used where chemical inertness is a requisite.

Acid-proof Cements.

Rubber is also an ingredient of some *acid-proof cements*, among which the following is of use in the laboratory for cementing glass apparatus: 12 parts of raw linseed oil are heated and 12 parts of pure masticated rubber dissolved in it; when quite fluid the solution is worked into a stiff putty with paper stock asbestos.[36] This putty does not get hard or crack, and will resist the action of hydrogen chloride gas.

Another acid-proof cement consists of 8 lbs. fine litharge and 8 lbs. red lead mixed with 10 lbs. flock asbestos; small quantities at a time are fed into a mixer with small quantities of boiled linseed oil—6 quarts in all.[36] This cement was used to caulk 3-inch socket joints in a pipe line carrying nitric acid of 17-56 per cent strength, and stood up nine months without a leak.

Trinidad Asphalt.

Trinidad asphalt was found in laboratory tests to be a satisfactory material to prevent the deteriorating effect of acid on concrete tanks, the specific conditions to be met being those found where copper ores were handled by a combined sulfuric acid and electrolytic method.[37]

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V. Bases and Alkaline Salts.

The term base was originally applied to metal oxides, such as iron oxide, which formed salts with acids, but its meaning has become extended (and by some restricted) to include substances which when dissolved give alkaline solutions, i.e. solutions rich in hydroxyl ions, OH^-. In other words, in solution hydroxyl ion is the universal base. The reaction occurring when caustic soda is dissolved in water, for example, is

$$NaOH \longrightarrow Na^+ + OH^-.$$

Salts of weak acids and strong bases are hydrolyzed in solution, and since the acid formed is but slightly ionized, an alkaline solution, i.e. one rich in hydroxyl ion, is the result of the more or less complicated equilibria reached. This may be approximately indicated in the case of sodium carbonate by

$$Na_2CO_3 + 2H_2O \longrightarrow 2Na^+ + 2OH^- + H_2CO_3.$$

Salts of this character will be considered with the bases themselves.

The commonest soluble bases met with industrially are

Caustic soda	sodium hydroxide	$NaOH$
Caustic potash	potassium hydroxide	KOH
Hydrated lime	calcium hydroxide	$Ca(OH)_2$
Ammonia water	ammonium hydroxide	NH_4OH

The insoluble bases, such as ferric oxide, Fe_2O_3, are for the most part inert towards the materials considered here except at high temperatures, and will therefore not require as extensive discussion as the soluble bases. With the exception of ammonia, the solutions of the bases in the above list behave very much alike in all chemical reactions, the chief differences being due to solubility differences of the bases themselves or of the products resulting from their reactions with other materials. Ammonia, however, besides behaving like a weak base *per se*, can enter into a quite different series of reactions through its ability to form complex salts and ions with a number of metals (e.g. cuprammonium sulfate, $Cu(NH_3)_4SO_4.H_2O$, and cuprammonium ion, $Cu(NH_3)_4^{++}$), and under some conditions to be oxidized to nitrous acid among other products.

Bases and Metals.

Solutions of the bases in water do not react appreciably with most of the metals (in fact the addition of a little sodium carbonate to water tends to lessen its corrosive action on iron and steel), but the four common metals, aluminum, zinc, tin and lead, are exceptions. The oxides of these metals behave like weak acids towards strong bases, and the metals themselves displace hydrogen from solutions of these bases. For example [1]

$$2NaOH + 2Al + 2H_2O \rightarrow 2NaAlO_2 + 3H_2$$

or in ionic terms

$$2OH^- + 2Al + 2H_2O \longrightarrow 2AlO_2^- + 3H_2.$$

Bases and Non-metallic Materials.

Towards industrial materials other than metals the bases, and especially strong alkaline solutions like the caustic lyes, are very active. For example they attack inorganic materials containing silica, such as glass, and decompose many silicates with the formation of soluble sodium or potassium silicates; they attack as well most classes of organic materials except hydrocarbons especially acids, esters and phenols or their derivatives, so that varnish gums, paint vehicles and synthetic resins (e. g. rosin, linseed oil, Bakelite) offer little resistance to them. The anhydrous alkalies, being strong dehydrating agents, quickly destroy or modify complex organic material such as flesh, wood, and textile fibers, and their concentrated solutions are nearly as or more active.

Iron.

The handling of alkalies and bases in general in the plant or in making shipments is much simplified for the engineer, in comparison with the similar problem arising in connection with the handling of acids, by the inertness of most metals, especially iron, towards them.

Both for apparatus handling alkalies and for structural parts exposed to their action iron is the most useful material. It receives its most drastic treatment in caustic fusion kettles, in which the temperature often exceeds 300° C. Under these conditions the cast iron, of which the kettles are usually made, is attacked, and provision must be made in setting the kettle for ready renewal. The life of such a kettle may be, roughly, as short as two months or as long as two years, according to the conditions under which it is used. Since most failures of such kettles are due to their being burned out, their life is somewhat prolonged by turning them occasionally in their brick mountings so that the hottest part of the flame used to heat them strikes them successively on different spots.[2]

Cast iron is used for caustic fusion kettles because it has been found to be less acted on by concentrated solutions or fused caustic soda. A high ratio of graphitic to total carbon[3] and the addition of 1-3 per cent nickel to gray cast iron[4] favor its resistance to alkalies. The action of alkalies on iron in cases like the above is probably due in part to the favoring catalytic action of alkalies on oxidation under some conditions and in part to the removal of oxides from the surface of the iron in the form of ferrates.[5] It is said to be accompanied by the evolution of hydrogen and preliminary solution of the iron as a green ferrous compound, followed by precipitation of brown ferric oxide.[6] An explanation advanced to cover the increased attack of strong caustic soda (31 per cent) on iron when air is blown through it is that under such conditions the iron is dissolved as a perferrate, e. g. $NaFeO_4$.[7]

Under the action of dilute alkaline solutions up to the boiling point and of concentrated solutions at moderate temperatures steel and ordinary cast and wrought iron stand up well, the choice of material for a particualr case depending upon the physical characteristics desired; ammonia, caustic soda and caustic potash solutions are commonly stored in tanks, handled with pumps through pipes and shipped in drums all of steel or wrought iron. It seemed practicable at one time to concentrate caustic soda in steam boilers to a specific gravity of 1.15 to 1.25, but this practice had to be abandoned because of corrosion due to the presence of sodium sulfide (Na_2S) in the liquor. When free of sodium sulfide, the caustic liquors of this concentration did not act appreciably on the boilers.[8]

A non-corroding steel manufactured by the Crucible Steel Co. is entirely unaffected by caustic soda solution, quicklime or pasty Portland cement.[7a]

Commercially pure iron behaves as shown in the following tables towards ammonium hydroxide and sodium hydroxide solutions. In the test with ammonia water, all the test pieces were immersed in hot, concentrated ammonia water in the same vessel for eight days, the ammonia being renewed daily. In the test with sodium hydroxide, the pieces were immersed in a 25 per cent solution at room temperature for 100 days.

ACTION OF HOT CONCENTRATED AMMONIUM HYDROXIDE SOLUTION ON IRON AND COPPER

	Total Loss, g./m.^{2}	Average Loss, g./m.^{2}/hour
Commercially pure iron	12.21	0.064
Mild steel	42.72	0.222
Metallic copper	628.7	3.27

ACTION OF 25 PER CENT SODIUM HYDROXIDE AT ROOM TEMPERATURE

	Total Loss, g./m.^{2}	Average Loss, g./m.^{2}/hour
Commercially pure iron	5.19	0.0216
Mild steel	24.11	0.100

Ferrosilicon Alloys.

These alloys, such as Duriron, that are so resistant to acids (see p. 36) are quite different from ordinary grades of iron in their behavior towards alkalies, which readily dissolve the silicon, thus disintegrating the whole mass; a few grams of solid caustic soda placed in the bottom of a Duriron test dish in a moderately heated muffle furnace will dissolve the bottom out in twenty minutes. This is so characteristic of all alloys of this class, that their reaction with alkalies has even been used for the commercial manufacture of hydrogen:[9]

$$\mathrm{Si} + 2\mathrm{NaOH} + \mathrm{H_2O} \text{ — } \mathrm{Na_2SiO_3} + \mathrm{H_2}.$$

Scale.—While metallic iron is not strongly attacked by alkaline solutions, boiling soda and caustic soda solutions are useful for cleaning scale from iron and steel in cases where the use of acid is excluded. This action may be due to a number of causes depending chiefly on the composition of the scale (whether, for example, it contains lime or other salts). Where the scale is old rust, the formation of ferrates may be a factor, though the major portion of the scale is dislodged and not dissolved.

Lead and Other Metals.

Since lead is easily attacked by the alkalies, special care must be taken wherever possible to prevent this attack in apparatus used successively for different liquids or for solutions varying in reaction, as for example, in neutralization tanks with lead acid lines and lead fittings. The action of very dilute alkalies is not marked, so here the consideration mentioned in a previous chapter comes into play: plant operation will be different in the case where the products must be kept free from appreciable traces of lead, from what it will be where only the avoidance of unusual wear on the apparatus is the aim; in the latter case more latitude of handling may be permitted. The same is true to a still greater degree where aluminum is concerned, but solid, dry caustic soda or potash are said to be without action on this metal even at a dull red heat.

The action of dilute alkaline solutions at room temperature is shown in the following table, the conditions of the test and the metals used being the same as those in the experiments described on p. 48.[11]

THE ACTION OF 0.2 N SOLUTIONS OF BASES ON METALS AT 17–20°

LOSSES IN GRAMS PER SQUARE METER PER HOUR

A. Action of ½ liter of solution renewed daily for 7 days.

Metal	$NaOH$	NH_4OH	Na_2CO_3
Zinc	0.18	0.21	0.01
Cast iron	0.00	0.00	0.00
Wrought iron	0.00	0.00	0.00
Aluminum	12.00	0.21	0.48
Lead	0.60	0.01	0.00
Copper	0.00	0.30	0.00
Tin	0.18	0.00	0.00
Nickel	0.00	0.00	0.00

B. Action of ½ liter of solution for 28 days, not renewed.

Metal	NaOH	NH_4OH	Na_2CO_3
Zinc	0.03	0.03	0.00
Cast iron	0.00	0.03	0.00
Wrought iron	0.00	0.00	0.00
Aluminum	0.39	0.00	0.02
Lead	0.10	0.00	0.01
Copper	0.00	0.05	0.00
Tin	0.08	0.00	0.00
Nickel	0.00	0.00	0.00

A comparison of the action of the three different solutions shows that ammonia and sodium carbonate act as weak bases in comparison with the strong base sodium hydroxide. Aluminum is exceedingly susceptible to the action of dilute sodium hydroxide, and lead is next, followed by zinc and tin. The action of ammonia on copper is explained by the ready formation of complex ions and soluble salts of the type above mentioned ($Cu(NH_3)_4^{++}$) which results in the solution in ammonia water of any coating of salts on the metal, and by the fact that ammonia in the presence of air and moisture attacks the metal itself to some extent, nitrites being among the products formed.[12]

Perfectly dry ammonia gas, NH_3, does not act on iron, copper or aluminum at ordinary temperatures, but at high temperatures some metals react with it to form nitrides:[13] Mn_3N_2 forms at 800°. Cr_3N_2 forms at 850°. W forms no nitride but decomposes some ammonia at high temperatures. Ti forms a compound insoluble in water or hydrochloric acid. Pb and Sn are frosted and blistered at 170°; no nitride is formed, but some ammonia is decomposed. Zn and Cd form nitrides.

Alkali Resistant Alloys.

On account of the resistance of iron to alkalies and alkaline solutions there has not been the same necessity for developing alkali-proof alloys as there has been for developing alloys resistant to acids. The behavior of the latter towards alkalies varies, ferro-silicon (as has been mentioned) being easily attacked, while stellite (50-60 per cent Cobalt, 30-10 per cent Chromium and 8-20 per cent tungsten) and nichrome are unattacked. The following table gives the conditions under which nichrome was tested:[15]

ACTION OF 4 M SODIUM HYDROXIDE SOLUTION ON NICHROME

	Loss in g./m.²/hr. during the periods			
Temperature	0–48 hr.	48–72 hr.	72–142 hr.	0–142 hr.
25°	0.00	0.00	0.00	0.00

	Loss in g./m.²/hr. in 4 hours
95–98°	0.07

Monel metal resists well the action of ammonia, solutions of ammonium hydroxide, fused and dissolved caustic alkalies and carbonates.[15a]

In general the action of alkaline solutions on the common alloys may be predicted qualitatively from their actions on the components of the alloys separately. Thus brass condenser tubes are attacked by strongly alkaline water because of the zinc they contain, and by ammoniacal water because of their copper,[16] anodes of ferro-manganese are decomposed in electrolyzing caustic soda solutions with the formation of permanganate at temperatures up to 95° and of manganate at higher temperatures,[17] etc.

Noble Metals.

Of the noble metals, platinum reacts with fused caustic alkalies, but not appreciably with their carbonates; gold is more resistant. The addition of sodium peroxide, Na_2O_2, greatly increases the rate of action on the metal. A series of experiments in which 5 g. of NaOH and KOH respectively were fused in crucibles of varying composition over an alcohol lamp (used to eliminate the effect of sulfur whose action would be felt if illuminating gas were used) gave the following comparable results:[18]

		Losses in Grams with	
	Composition of Crucible	NaOH	KOH
1a	Pure Pt, old	0.034	0.130
1b	" " new	0.024	0.110
2	95 Pt, 5 Ir	0.046	0.135
3	90 " 10 "	0.075	0.141
4	98 " 2 Cu	0.0355	0.0895
5	Pure Au	0.005	0.0065
6	75 " 25 Ag	0.0035	0.003
7	10 " 90 "	0.0045	0.0065
8	88 " 12 Pt	0.0065	0.011
9	60 " 40 Pd	0.0005	0.001
10	70 " 30 "	0.0005	0.001
11	73 " 27 " (rhotanium)	0.0002	0.0002

The losses with a Na_2O_2 and NaOH mixture were studied with crucibles 9 and 10. The losses increased with an increase in sodium peroxide content, and were less when chromite was present (as in an analytical operation). Between 62 and 65 per cent of the peroxide was required in the mixture for the complete decomposition of the chromite.

	Losses in Grams	
Crucible	Without Chromite	With Chromite
9	0.537	0.147
10	0.634	0.493

On decomposing Ba $(NO_3)_2$ at 825° C. the losses were:

Crucible	Losses in Grams
1a	0.0075
1b	0.0035
2	0.015
3	0.023

Non-metallic Materials.

Silicious Materials.

Most materials containing silica, a category including concrete, glass, tiles, enamels, etc., are attacked more or less rapidly by alkalies and other bases, though the great insolubility of most silicates makes the action slow at ordinary temperatures and with dilute solutions. For example, fused silica, an extremely insoluble and resistant substance, is attacked strongly at high temperatures by caustic alkalies and basic metal oxides, such as the oxides of copper and lead,[19] but concrete tanks, consisting largely of a mixture of calcium and aluminum silicates may be used for the storage of dilute alkaline solutions if they are cold.[4] In the latter case there is a slow reaction between the ingredients of the cement and the solutions, during the course of which the strength of the concrete gradually increases to a maximum and then falls off.[20] The eventual disintegration of the concrete (a matter of years with dilute solutions) is due to the formation of products more soluble than the original cements.

Glass.

When alkaline solutions come in contact with glass, especially if they are hot and concentrated, they dissolve and etch the surface of the glass; the action is very much greater than that of acid solutions under similar conditions. The following table[21] shows the action of ammonia and sodium carbonate solutions on eight glasses whose analyses are given on page 98.

LOSS IN MILLIGRAMS UNDERGONE BY CHEMICAL GLASSWARE ON BEING TREATED WITH 300 C.C. OF REAGENT AT THE BOILING TEMPERATURE FOR THREE HOURS

	Sample	Ammonia 50%	Sodium Carbonate 0.1 N
A	French	10.0	20.5
B	"	6.5	51.0
C	"	8.5	27.0
D	Jena	4.0	14.0
E	Kasna, Bohemia	12.5	122.0
F	Kavalier, "	8.0	103.0
G	Thuringian	5.0	27.0
H	"	6.0	37.0

Comparative tests carried out at the Bureau of Standards[22] on the behavior of seven glasses towards alkaline solutions resulted in the following grading:

ACTION OF ALKALINE SOLUTIONS ON LABORATORY GLASSWARE

Glass	Alkali Carbonates	Caustic Alkalies	Ammonium Salts and Ammonia
Kavalier	P	G^2	G^2
Macbeth-Evans	G^2	G^1	G
Pyrex	G^3	F	G
Jena	G^2	F	G
Nonsol	G^1	F	G
Fry	G^2	F	G
Libbey	G^3	F	G

G: good; F: fair; P: poor. Exponents indicate order of excellence, 1 being best.

Analyses of these glasses are given on page 99.

In another investigation the following glasses (for analyses see page 101).

A	Prewar Jena	N	Frey, American
B	———	O	Pyrex, "
C	British	P	Resistance R, German
D	"	Q	Kohn, Ehrenfeld, German
E	"	R	Kavalier, "
F-J	———	S	———
K	Japanese	T	Insol, American
L	Nonsol, American	U	Zsuola, German
M	Insolo, "	V	Macbeth-Evans, American

were tested for their resistance to alkalies[23] by heating for 3 hours at 100° C. with (a) 2N NaOH, (b) 0.1 N NaOH, and (c) 0.1N Na_2CO_3, and repeating in each case three times. The glasses were graded as good, moderate and bad, the limits in each class, expressed as milligrams loss per square decimeter exposed, being:

	2 N NaOH	0.1 N NaOH	0.1 N Na_2CO_3
Good	235.8–312.5	41.0–65.4	74.1–96.8
Moderate	343.4–387.6	84.4–98.3	108.1–153.3
Bad	470.3	111.3–136.8	263.3–600.7

and the grading as follows in descending order of excellence in each class:

GRADING OF LABORATORY GLASSWARE ACCORDING TO ITS RESISTANCE TO ATTACK AT 100° C.

Grade	2 N NaOH	0.1 N NaOH	0.1 N Na_2CO_3
Good	G P T D Q V S B N E L R K C M F	Q G T F D V N B E C M A P	D Q E P C F V L B A T
Moderate	I O J A	R I O S	G N M O
Bad	H	J H	I J S R H

Porcelain.

Porcelain, like glass, is attacked and etched by alkalies, though in general it is more resistant than glass.

Asbestos.

Asbestos cloth diaphragms, specially prepared to resist the action of both strong alkaline solutions and chlorine, have been used in electrolytic cells for caustic potash.[21]

Organic Materials.

Of the organic materials that call for consideration wood and rubber are undoubtedly the most important from an engineering point of view, with the textiles a close second.

Wood.

The action of various basic solutions on wood has been studied in the same manner as that of acid solutions (see p. 104).[25] The relative effect of six woods on the color of solutions contained in tanks made of them is shown in the following table on a scale of 4, in which 1 indicates little and 4 strong coloration.

RELATIVE EXTRACTION OF COLORING MATTER FROM WOODS BY ALKALINE SOLUTIONS

Solution	Cypress	Long Leaf Pine	Douglas Fir	Red-wood	Hard Maple	White Oak
1% NaOH	2	3	3	3	3	3
Concentrated NaOH	3	3	4	4	4	4
Satd. $Ca(OH)_2$	2	2	2	3	2	3
5% bleaching powder	1	2	2	2	2	2
Na_2S	4	4	4	4	4	4
5% Na_2CO_3	2	3	3	3	3	3

The relative absorption of these solutions by the same woods is shown on the same scale in the following table; since no relation between the concentration of the solution and the amount absorbed was apparent, the results are averages for several concentrations.

RELATIVE ABSORPTION OF ALKALINE SOLUTIONS BY WOODS

	Cypress		Douglas Fir		Long Leaf Pine		Red-wood		Hard Maple		White Oak	
Solution	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold
NaOH	4	4	4	4	3	4	4	4	4	4	4	4
Na_2CO_3	4	2	4	3	4	2	4	4	4	4	3	3
Na_2S	4	4	4	4	4	4	4	4	4	4	4	4
$Ca(OH)_2$	4	4	4	4	2	2	4	4	4	4	4	4
Bleaching powder	2	2	2	2	2	2	3	3	4	4	2	2

The effect of these solutions on the physical properties of the woods is shown in the following table in which are summarized the statements of the investigators. A minus sign indicates no appreciable effect on the wood, while a positive sign indicates attack of some sort, such as brittling, softening or undue shrinking. Signs in parentheses indicate conclusions by inference from the authors' direct statements.

EFFECT OF ALKALINE SOLUTIONS ON PHYSICAL PROPERTIES OF WOODS

Solution	Cypress	Douglas Fir	Long Leaf Pine	Red-wood	Hard Maple	White Oak
1% NaOH cold...	—	(—)	—	+	+	+
10% " " ...	—	..	—	(+)	(+)	(+)
10% " hot ...	—	..	—	(+)	(+)	(+)
25% " cold...	(+)	(+)	—	(+)	(+)	(+)
20% Na_2S " ...	—	—	—	+	—	+
Na_2CO_3 hot	—	—	—	+	—	+

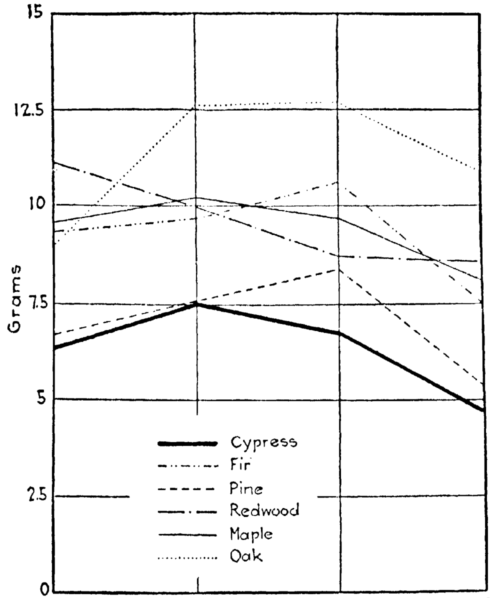

FIG. 18.—Liquid Absorbed. NaOH at Varying Concentrations.

The results of another series of experiments are given in the next table and in the accompanying figures. In the table S indicates any softening effect, W indicates warping, splitting, distortion or the like, and a blank indicates no test (see p. 110).

EFFECT OF SODIUM HYDROXIDE SOLUTIONS ON WOOD

NaOH (Sodium Hydroxide)	Cypress		Fir		Pine		Redwood		Maple		Oak	
	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot
1%	.....	.....	.....	W	.....	.....	S, W	S	W	W	W	W
5	.....	.....	.....	W	.....	.....	S, W	S	W	W	W	W
10	.....	.....	W	W	.....	W	S, W	S, W	W	W	W	W
25	.....	.....	W	W	.....	W	S, W	S, W	W	W	W	W

Rubber.

Rubber is extremely inert towards alkalies, and pure vulcanized rubber in the form of hose, tubing, stoppers or the lining of chemical apparatus, such as pipes, tanks, centrifuge baskets, etc., (see page 120) successfully resists the action of strong sodium hydroxide or carbonate solutions, ammonia and ammonium salts.[26]

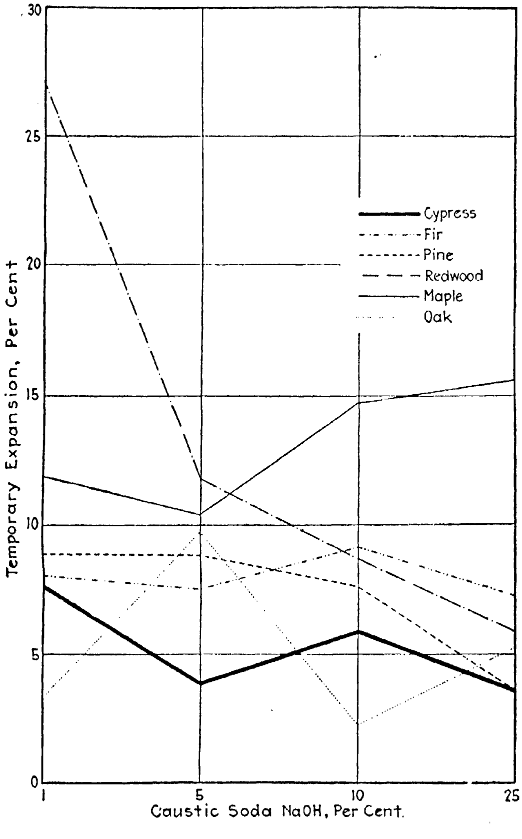

FIG. 19.—Expansion in NaOH at Different Concentrations.

Textiles.

As was pointed out in the previous chapter the common textile fibers of respectively animal and vegetable origin are sharply differentiated from each other by their behavior towards acids and alkalies, cotton, for example, resisting the action of alkalies well, but being easily destroyed by dilute acids, while wool, on the other hand, is destroyed by alkalies, and but little affected by acids.

Cotton.

While cotton is not easily destroyed by alkalies, the fiber undergoes a marked change when treated a short time with cold concentrated sodium hydroxide solutions—Mercerization. The fiber acquires a luster resembling that of silk, and at the same time shrinks. Since different yarns vary in their behavior considerably, the concentration of sodium hydroxide used to produce this effect is likewise varied, the limits being in the neighborhood of 15 and 30 per cent.[27] Weaker solutions produce no visible change even when hot; experiments in which crude cotton piece goods were treated on the jigger with respectively 5, 8 and 13 per cent sodium hydroxide, well washed, boiled out under pressure, and bleached, showed no mercerization, but some loss in weight and a slight increase in tensile strength, probably due to the formation of some hydrocellulose from the cellulose of the fiber.[28] Other strong bases behave similarly to sodium hydroxide: e. g., potassium, lithium and tetramethyl ammonium hydroxides (KOH, $LiOH$, $(CH_3)_4NOH$), the latter a substituted ammonium derivative[29] (see below).

Ammonia alone, being a weak base, has no effect on cotton, but an ammoniacal solution of copper hydroxide dissolves the fiber, as does a mixture of sodium or potassium hydroxide and carbon disulfide; an ammoniacal solution of nickel oxide scarcely dissolves cotton (cf. silk, below).

Wool.

Very dilute alkaline solutions weaken the wool fiber, and boiling 5 per cent sodium or potassium hydroxide completely dissolves it. If wool is warmed with 1 per cent sodium hydroxide, damage is apparent at 40°; at 70° the outer layer of the fiber is loosened, and in 15 minutes at 80° the separation of the outside layer is complete. Hot, strong solutions of ammonia are perceptibly harmful, and it is probable that scouring baths containing as much as 10 per cent sodium carbonate are responsible for some accidental damage.[30] Weakly alkaline soap baths kept below 60° are harmless.

Strong sodium hydroxide solutions (40-50 per cent)at ordinary temperatures have quite a different effect, producing changes similar to those occurring in the mercerization of cotton (see above) and increasing its tensile strength.[31]

The destructive action of dilute alkalies on wool is accounted for, according to one theory, by the existence of a carbohydrate, elasticum, between the scales (plate cells) and body (fiber cells) of the fiber, which is responsible for the felting properties and much of the strength and flexibility of wool. Treatment of the fiber with 2 per cent sodium hydroxide at 25° or less for 24 hours is sufficient to remove all the elasticum from the fiber, thus destroying its felting properties and making it weak and brittle.[32]

Silk.

Silk is more resistant to dilute alkalies than is wool, but the fiber is dissolved by solutions of alkaline hydroxides, ammoniacal copper or nickel oxides, and basic zinc chlorides.[23] Ammonia alone has no effect. In contradistinction to wool and cotton, silk is also dissolved by an alkaline solution of copper sulfate in glycerine (16 g. copper sulfate and 10 g. glycerine are dissolved in 150 c.c. water, and a sodium hydroxide solution is added until the first formed precipitate is redissolved).[34] Boiling hard water or alkali carbonate solutions make the silk fiber brittle.

Paint and Varnish.

Strong caustic alkalies attack and quickly destroy ordinary paint and varnish surfaces by saponifying and partly dissolving the esters and acids that largely constitute paint vehicles and varnish resins; weaker alkalies, such as ammonia and weak alkali carbonate solutions, attack paints and varnishes more slowly but with an eventual deteriorating effect. For this reason sodium hydroxide solutions are often used for removing old paint from surfaces to be repainted; and for the same reason in washing painted surfaces, especially gloss surfaces such as those of automobiles and carriages, the use of soap has a deteriorating effect unless the soap is neutral and contains no free alkali or alkali carbonate.

Paints made with an asphaltum base dissolved in a hydrocarbon vehicle are more resistant to the action of alkalies.

Artificial Resins.

The most widely used artificial resins, the phenol-formaldehyde condensation products, are also attacked by alkalies, though much less vigorously than the natural resins. Strong boiling caustic soda solutions will disintegrate even those products carried to an advanced stage of condensation, that is until they are infusible and insoluble in organic solvents at ordinary temperatures and pressures.

Other Alkalies.

It remains to mention briefly a few alkaline substances that are not commonly met with commercially. Besides the metallic oxides and hydroxides, the other bases (for the purpose in hand) are all nitrogen compounds, and derived from the three substances ammonia, hydroxylamine and hydrazine (NH_3, NH_2OH and N_2H_4).

Substituted ammonias or ammonium compounds are those in which some other element or group of elements takes the place of one or more hydrogen atoms of the ammonia molecule. Sodamide ($NaNH_2$) is a solid substance which reacts violently with water, explodes when ground in the air, and is used in organic syntheses because of its reactivity with organic compounds. Monomethyl-, dimethyl- and trimethyl amines (NH_2CH_3, $NH(CH_3)_2$ and $N(CH_3)_3$), as well as the corresponding ethyl (C_2H_5-) compounds are gases or volatile liquids resembling ammonia chemically, while the related tetramethyl ammonium hydroxide ($N(CH_3)_4OH$) corresponds to ammonium hydroxide in structure but resembles the solid caustic alkalies in behavior. Both it and the corresponding ethyl compound are strongly basic solids.

Hydroxylamine (NH_2OH), a white volatile solid which explodes when heated, and its hydrate ($NH_3O.OH$) are bases, but weaker bases than ammonia and ammonium hydroxide.

Hydrazine hydrate ($N_2H_4.H_2O$), a white solid formed by the addition of water to hydrazine (N_2H_4), is a strong and corrosive base that attacks glass, rubber, cork and other substances. It forms many complex organic derivatives.

Hexamethylenetetramine $(CH_2)_6N_4$ is a white, crystalline powder that acts as a weak base, and has recently become important because of its use in synthetic resins, as well as for various other purposes. In aqueous solution it attacks iron and is best handled in enamelled iron equipment. It also attacks aluminum, copper, Monel metal and lead. Iron containers, however, are used for shipping the solution without apparent harm, owing to the formation of a film which resists further attack.[35]

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VI. Neutral Substances.

Besides the acids and bases and their more or less acidic or basic salts, many substances that for the purpose in hand may be called neutral have an interest for the industrial chemist or engineer because of their chemically destructive action on engineering materials; chief among these are the halogens, chlorine, bromine and iodine, and their organic and inorganic derivatives. Oxygen and sulfur may be added to the list, and in certain cases some of the metals themselves come in for consideration.

Halogens.

The halogens attack all metals and many non-metallic elements, as well as most organic substances, but the presence of some other substance acting as a catalyst is usually necessary in order that the reaction reach an appreciable velocity. Dry liquid chlorine acts so slowly on iron and steel at ordinary temperatures that it is commonly stored in steel cylinders and tanks under pressure. In addition to wrought and cast iron and steel, the metals copper, zinc, lead, and the alloys brass and phosphor-bronze are unacted on at moderate temperatures by dry chlorine either alone or in contact with strong sulfuric acid.[1] Bromine and iodine are chemically similar to chlorine, but are less reactive in the order named; the most active halogen, fluorine, is technically unimportant.

Water is the commonest catalyst favoring the action of halogens on metals. When chlorine dissolves in water, it reacts to form small amounts of hydrochloric and hypochlorous acids, (HCl, $HClO$):

$$Cl_2 + H_2O \rightarrow HCl + HClO.$$

The latter is unstable and an active oxidizing agent. Chlorine water, therefore, containing chlorine, hydrochloric and hypochlorous acids, is strongly corrosive, and by virtue of the above reaction or some more obscure catalytic effect of small amounts of water, moist chlorine readily attacks metals. The difference between moist and perfectly dry chlorine is illustrated by the fact that thin copper foil (Dutch leaf) ignites and burns spontaneously on being introduced into an atmosphere of chlorine containing a trace of moisture, while in dry chlorine there is no apparent reaction.[3] Monel metal resists the action of dry chlorine fairly well.

At high temperatures even dry chlorine unites vigorously with metals, and iron and aluminum, if heated sufficiently to start the reaction, burn violently in it.

Tile and chemical stoneware are used largely in handling chlorine and bromine at atmospheric pressure, and stills for the production of chlorine from hydrochloric acid and manganese ore were made of siliceous sandstone often impregnated with tar.

Very few, if any, of the technically used organic compounds, such as rubber, paints, etc., are able to withstand the action of free halogens.

Acyl Chlorides.

The halogens form a series of compounds, the acid or acyl halides, that may be considered derived from the acids, inorganic and organic, by the substitution of one or more halogen atoms for one or more acid hydroxyl groups. In this series the chlorine compounds are of considerable technical importance. Some of these compounds with their melting and boiling points are given in the following list opposite the acids to which they are related.

Acid	Acid Chloride	M.P.	B.P.
Carbonic, $CO(OH)_2$	Phosgene, $COCl_2$	...	8°
Ortho-silicic (hypothetical), $Si(OH)_4$	Silicon tetrachloride, $SiCl_4$	-89°	57
Ortho-titanic, $Ti(OH)_4$	Titanium " $TiCl_4$	-25	136
Stannic acid, $Sn(OH)_4$	Stannic chloride $SnCl_4$	-33	120
Ortho-phosphoric (hypothetical), $P(OH)_5$	Phosphorus pentachloride, PCl_5	148	...
Ortho-phosphoric (ordinary), $PO(OH)_3$	" oxychloride, $POCl_3$	2	110
Phosphorous acid, $P(OH)_3$	" trichloride, PCl_3	-112	76
Sulfuric acid, $SO_2(OH)_2$	Sulfuryl chloride, SO_2Cl_2	...	71
" " "	Phosphorus pentachloride, PCl_5	-39	146
Pyrosulfuric acid, $S_2O_5(OH)_2$	Chlorosulfonic acid, $SO_2.OH.Cl$	...	158
Sulfurous acid, $SO(OH)_2$	Thionyl chloride, $SOCl_2$	...	78
Selenic acid, $SeO_2(OH)_2$	Selenyl chloride, SeO_2Cl_2	...	
Acetic acid, CH_3COOH	Acetyl " CH_3COCl	...	56

All these chlorides, with the exception of phosphorous pentachloride, are liquids easily (some explosively) hydrolyzed by water to hydrochloric and the mother acid. In contact with water or moist air they are, therefore, corrosive towards metals affected by these acids. When dry, however, they react quite differently.

Sulfuryl chloride scarcely reacts with the heavy and the noble metals at ordinary temperatures, and the German railways have authorized the substitution of shipments in steel tank cars for the previously authorized shipments in 60 kg. glass carboys or 500 kg. drums. At higher temperatures, however, reaction occurs with iron, platinum and gold, with the formation at 150-160° of $FeCl_3$, $PtCl_3$ and $AuCl_3$ respectively; no reaction occurred with silver, zinc or cadmium. With mercury the reaction proceeds according to the equation:[2]

$$Hg + SO_2Cl_2 \longrightarrow HgCl_2 + SO_2.$$

Thionyl chloride reacts with iron, bismuth, gold, tin, antimony and arsenic in sealed tubes at 150-200° according to the equation:

$$3M + 4SOCl_2 \longrightarrow 3MCl_2 + SO_2 + S_2Cl_2$$

or with excess metal according to:

$$3M + 2SOCl_2 \longrightarrow 2MCl_2 + MS + SO_2$$

where M is a bivalent metal. If an excess of thionyl chloride is present, beyond that called for by the first equation, the lower chlorides of iron, tin and antimony are oxidized to the higher. Zinc, cadmium, magnesium, chromium and nickel do not react at or below 200°.[4]

Some of the poison gases developed during the Great War consist of or contain one of the acid chlorides listed above. Phosgene, silicon tetrachloride, titanium tetrachloride, and chloropicrin (CNO_2Cl_3) mixed with tin tetrachloride have been kept in closed iron containers a minimum of 20 months without change and without appreciably attacking the iron. Mustard gas ($(C_2H_4Cl)_2S$) shows less change than might be expected.[5]

Sulfur monochloride (S_2Cl_2), a reddish yellow liquid boiling at 138°, resembles the acid chlorides in being a reactive substance easily hydrolyzed by water:

$$2S_2Cl_2 + 2H_2O \longrightarrow SO_2 + 4HCl + 3S.$$

It is very corrosive, attacking, for example, iron, tin, aluminum and mercury (moisture absent?) to form the corresponding chlorides, and its vapor reacts with metal oxides at high temperatures.[6] A solution of sulfur in sulfur monochloride is used in the cold vulcanization of rubber.

The acid chlorides, especially those of the sulfur, selenium and phosphorus acids, attack many classes of organic compounds, either dissolving them without deep seated chemical change, or replacing oxygen ($:CO$) or hydroxyl ($:COH$) groups with chlorine ($:CCl_2$ and CCl). Several recent patents have been granted for the preparation and use of selenyl chloride as a solvent.[7]

Organic Halides.

A large class of organic compounds exists, many of whose members are of considerable industrial importance, in which one or more hydrogen atoms of a hydrocarbon molecule have been replaced by one or more halogen atoms. Many of these compounds are used in organic syntheses because of their reactivity, while others find technical application because of their solvent powers. Chloroform, $CHCl_3$, carbon tetrachloride, CCl_4, Dutch oil, $C_2H_4Cl_2$, and benzyl chloride, $C_6H_5CH_2Cl$, are examples of this group, all characterized by the fact that they contain carbon and a halogen, with or without hydrogen. Other substituents may be present, as in chloropicrin, CCl_3NO_2, monochloracetic acid, $CH_2Cl.CO_2H$, etc.

An extensive study has been made of the action of these compounds on metals because of the importance of their behavior in metal containers.[8] The results of preliminary experiments showed that carbon tetrachloride does not react with nor corrode iron, tin or copper if moisture is absent; when the carbon tetrachloride is moist, there is corrosion, and when aqueous ammonia is present, the corrosion is very rapid. Further experiments warranted the generalization that, with certain exceptions, organic halides in contact with aqueous ammonia acted corrosively on copper (and probably on other base metals), if they contained a trihalomethyl group in the molecule, CX_3 (where X = chlorine, bromine or iodine). In the following table a number of compounds are classified according to their power to dissolve copper in contact with strong aqueous ammonia at room temperature.[9]

ACTION OF ORGANIC HALIDES AND STRONG AQUEOUS AMMONIA ON COPPER AT ROOM TEMPERATURE

Rapid Solution	Slow Solution	No Solution
Carbon tetrachloride, CCl_4	Iodoform, CHI_3	Ethyl bromide, C_2H_5Br
Chloroform, $CHCl_3$	Ethylene chloride, $(CH_2Cl)_2$	Ethylene bromide, $(CH_2Br)_2$
Bromoform, $CHBr_3$	Ethylidene chloride, $CH_3.CHCl_2$	Ethyl iodide, C_2H_5I
Hexachlorethane, C_2Cl_6	Acetylene tetrachloride, $(CHCl_2)_2$	Benzyl chloride, $C_6H_5CH_2Cl$
Pentachlorethane, C_2HCl_5	Benzotrichloride, $C_6H_5.CCl_3$	Epichlorohydrin, $CH_2.CH.CH_2Cl$
Chloral, $CCl_3.CHO$		Allyl bromide, C_3H_5Br
Chloropicrin, CCl_3NO_2		Monochloracetic acid, $CH_2Cl.CO_2H$
Ethyl trichloracetate, $CCl_3.CO_2.C_2H_5$		Tetrachlorethylene, $(CCl_2)_2$
Dichloroacetic acid, $CHCl_2.CO_2H$		p-Dichlorobenzene, $C_6H_4Cl_2$
Trichloracetic acid, $CCl_3.CO_2H$		p-Chlorotoluene, $C_6H_4CH_3.Cl$
		Tribromophenol, $C_6H_2Br_3OH$

The use of silver electrodes for electrolytic determinations of copper has been made possible by the discovery of a suitable solvent for the copper, the lack of such a solvent having been the chief drawback hitherto; an ammoniacal solution of ammonium trichloracetate ($CCl_3.CO_2NH_4$) dissolves the copper from the electrode, leaving the silver unattacked and consequently unchanged in weight.[9]

Chlorinated hydrocarbons are almost insoluble in water but unless specially treated contain a certain amount of moisture. They are very stable substances, resisting the action of a large number of chemicals, yet in the presence of moisture and under the influence of heat many of them are liable to slow decomposition, especially if they are impure. Data on carbon tetrachloride and tetrachloroethane are given in the following table:

	Carbon Tetrachloride	Tetrachloroethane
Formula	CCl_4	$CHCl_2.CHCl_2$
Color	Colorless liquid	Colorless liquid
Properties	Heavy vapors, non-inflammable, poisonous	3 times as toxic as chloroform (Velley, Roy. Soc. Proc. 1910, B.82, 217-225). Slightly anæsthetic (Clement and Rivien, C. & G. P. 1910, 7. 4021).
Specific gravity	1.5835	1.60
Boiling point	76.74° C.	147° C.
Solubility	Alcohol and ether; water, slightly	Alcohol and ether; water, insoluble

A series of experiments was carried out to ascertain the effect of these hydrocarbons on metals in the presence of moisture,[10] and since a number of oil-seeds are extracted by these solvents, some of the experiments were done in the presence of oil-seeds (coconut, ground nut, and linseed) and some without the seeds. Thin strips of metal (1½ x ½ in.) were heated with the solvent under a reflux condenser for 10 hours, and the influence of the solvent examined by weighing the metal before and after the experiment. The solvents were used as obtained from stores, without purification, and no precautions taken to exclude moisture. Care was taken to see that they were neutral before being used. The seeds used contained some moisture. When the metals were used in contact with fatty material, they were thoroughly washed with ether and dried before weighing. The following table gives the results with any losses given as applying to a surface of ½ sq. in. for 10 hours:

	Mild Steel	Wrought Iron	Nickel	Copper	Aluminum	Lead
Carbon Tetrachloride						
With seeds	nil	nil	nil	0.0025	nil	0.0015
By itself	"	"	"	0.0050	"	slight
Tetrachloroethane						
With seeds	0.0050	0.0050	0.0008	0.0090	completely destroyed	0.0040
By itself	0.0140	0.0150	0.0035	0.0150		0.0062

The important fact should not be forgotten that in a factory the materials are in contact for *years* and not for *10 hours.*

An old specimen of carbon tetrachloride, which had been for a long time exposed to air, moisture, and sunlight, gave greater losses than those shown above but the results could not be verified by a duplicate experiment owing to lack of material.

Tetrachloroethane gave most divergent results and those quoted are the mean. In the case of this solvent the smallest amount of moisture is sufficient to start the decomposition. After this solvent had been dried over calcium chloride for 15 hours and then redistilled and the fraction distilling at 146-147° C. collected, it still attacked the metals to an appreciable extent, the attack on aluminum beginning immediately on the commencement of boiling. Since tetrachloroethane boils at 147° C. no great amount of water can exist in solution at that temperature, yet the decomposition takes place.

A tentative view put forward is that under the influence of heat and in the presence of metals tetrachloroethane loses a molecule of hydrogen chloride, giving trichloro ethylene as follows:

$$CHCl_2.CHCl_2 = HCl + CCl_2:CHCl.$$

The acid would then act on the metals. This seems an improbable and unnecessary hypothesis, since it is well known that zinc (Frankland and Kolbe) and sodium (Würtz) react directly with alkyl halides, eliminating part or all of the halogen and introducing double or triple bonds.

Other Substances.

A number of miscellaneous reactions recorded in the literature call for mention, but are hard to classify, because they touch only isolated fields.

Mercury is of course very destructive on lead plumbing and apparatus, forming an amalgam of little strength. Iron and aluminum in contact with mercury in the presence of moisture are rapidly corroded and changed to oxides or hydroxides.[11] Mercury also amalgamates easily with gold and gold plated apparatus, but attacks platinum with difficulty. Monel metal resists the action of dry mercury excellently.

Fused zinc attacks ferro-silicon; experimental results show a loss in weight of the ferro-silicon at 420-450° of 18 g. per sq. m. per hour in an experiment lasting 48 hours. Fused lead and zinc attack Monel metal.

Ozone, O_3, at moderate temperatures attacks metals, e.g., silver, that are unattacked by ordinary diatomic oxygen, O_2, under the same conditions. Many metals when finely powdered, e.g., aluminum, burn with explosive violence on being heated in air, and all the base metals burn with more or less intensity when heated to a high temperature in an atmosphere of pure oxygen.

Sulfur at its boiling point attacks copper with great rapidity. Pieces of hard drawn copper rod, 3/8 in. in diameter by 5/8 in. long, immersed in boiling sulfur lost 15 per cent of their weight in 5 minutes, 86 per cent in two hours, and in four hours completely disappeared; a sulfide shell formed and increased at the expense of the metal.[12] Iron reacts violently when heated in intimate contact with sulfur.

Phenol, C_6H_5OH, and the cresols, $C_6H_4.CH_3.OH$, have no effect on copper in the absence of oxygen, but attack the metal when oxygen is present. Phenol reacts to form apple-green crystals containing, when air dried, 40.4 per cent copper; orthocresol in a similar reaction absorbs oxygen ten times as fast as phenol.[13] Phenol and the cresols have little action on Monel metal.

Neither cold nor boiling U. S. P. formaldehyde has any action on stellite; cold U. S. P. tincture of iodine is also without action, but the vapor from the hot tincture is corrosive.

Acetylene, C_2H_2, reacts with the moist or dissolved salts of some metals to form acetylides of the formula C_2M, where M is a divalent metal. The acetylides are of importance as dangers to be avoided because some of them, as for example those of copper and silver, are explosive, and may be formed accidentally by the action of acetylene on moist, corroded brass, copper or silver plate. Dry acetylene does not react with lead, copper, cadmium, tin, aluminum or zinc at temperatures up to their melting points as far as can be observed by change in the physical properties of the metals or in their carbon contents, but nickel cobalt and, to a less extent, manganese, tungsten, platinum and palladium react markedly in the order named. Carburization was effected with iron, but the strength of the metal was not lessened. Nickel and cobalt became decidedly brittle between 200 and 600°, and suffered corrosion and pitting.[14]

The long continued action of mineral oils on concrete or cement has a weakening effect; animal and vegetable oils are saponified by the action of basic calcium salts in the cement, with which they form calcium soaps, but their action is less on hardened carbonated cements than on other types.[15]

Monel metal stands up well under the action of gasoline and other mineral oils.

Mustard in liquid form (i.e. prepared mustard for the grocery trade) acts vigorously on all metals, including tin and silver, forming black compounds which stain the product. Hard rubber is entirely satisfactory for this difficult substance.

Molasses corrodes iron, steel, copper, brass, white bronze and zinc slowly. Monel and aluminum are unaffected.

Photographic Chemicals.

It is important in commercial photographic work to have available for photographic solutions large containers that are affected by and affect these solutions as little as possible. Since these solutions are relatively complex, special investigation is necessary to determine their effect on materials for tanks, trays, etc.[16] The results of such an investigation are summarized below.

For metals and metallic materials the following method of testing was used. Strips of metal, 2 x 4 in. and approximately 20 gage in thickness, were placed in 250-c.c. Pyrex beakers containing 200 c.c. of solution. Usually duplicate sets were made up, one set being kept at room temperature, 65 to 70° F., and the other at a tropical temperature, 110 to 120° F. Examination was made at the end of 24 or 48 hrs., 1 wk., 2 wk., and if the test was of sufficient interest it was continued for a longer period. The volume was kept constant by adding water at regular intervals.

In each case, the following observations were made:

1—*Appearance of the Solution.*—In the case of developers, the fog, which was produced on motion picture positive film after 15 min., was measured by means of the usual type of densitometer.

2—*Effect on the Metal.*—Inspection was made with the aid of a microscope.

The metals and alloys:

Metals	*Plated Metals*	*Alloys*
Aluminum	Galvanized iron	Aterite No. 136 (Cu-Ni-Zn)
Copper	Tinned iron	Brass (commercial sheet)
Iron		Duriron
Lead		Monel
Nickel		Niaco (Ni alloy)
Tin (block)		Nickel Silver (Cu-Ni-Zn-Fe)
Zinc		Nicolene (Ni-Cu)
		Phosphor bronze (Cu-Sn-P)
		Solder A (80% Pb-20% Sn)
		Solder B (20% Pb-80% Sn)
		Rezistal steel (Cr steel)
		Type metal (Pb-Sb)

were tested with the following photographic chemicals:

1—*Developers.*—(NOTE: The formulas are expressed in abbreviated form—namely, the number of grams of each constituent in a liter of solution ready to use—arranged in the following order: reducing agent, sodium carbonate (dry); sodium sulfite (dry); potassium bromide.)

(*a*)	Elon-hydroquinone (low elon content)	Elon 2.3 Hydroquinone 0.2-48-96-2
(*b*)	Elon-hydroquinone (high elon content)	Elon 4.0 Hydroquinone 1.0-20-10-0.5 Sodium bisulfite 10
(*c*)	Pyro (two solution)	Pyro 10-37·5-35-0.5 Sodium bisulfite 8.5

2—*Fixing Baths.*

(*a*) 30 per cent hypo solution

(*b*) Acid hypo solution (formula in grams per liter)

Hypo	Sodium sulfite	28 per cent acetic acid	Potassium alum
300	4.5	25 cc.	3.0

(*c*) Partially exhausted acid hypo solution (*b*) containing dissolved silver

(*d*) Completely exhausted acid hypo solution (*b*) containing dissolved silver

3—*A Hypo-alum Toning Bath*, containing potassium alum, hypo, silver nitrate, and sodium chloride.

4—*Water.*—Information as to the effect of moisture on the materials was desired in order to determine the most suitable metal or alloy for constructing washing and rinsing tanks.

5—*Dilute Acids.*—The photographer often has occasion to use solutions of dilute acids, and a number of the metals and alloys were tested to determine their relative resistance to dilute nitric and sulfuric acids.

The results obtained with the first elon-hydroquinone developer (*a*) after one day and at the end of a week at a temperature of 110° F. are given in the table. Tests made with Developers *b* and *c* confirmed these results.

ELON-HYDROQUINONE DEVELOPER *vs.* METALS AND ALLOYS

(Temperature, 110° to 120° F.)

Abbreviations:

Condition of Solution: D, darker than blank; L, lighter than blank; MD, much darker than blank; NC, no change; Ppt., precipitate.

Condition of Metal: C, corroded; Dp, deposit on surface; E, etched; S, stained; U, unchanged.

	24 Hrs.			One Week		
	Condition of		Fog	Condition of		Fog
Metals	Solution	Metal	Density	Solution	Metal	Density
Tin	Ppt.	U	1.26	Ppt.	E	0.76
Copper	NC	E	0.50	D-Ppt.	E-C	0.41
Aluminum	D-Ppt.	Dp-E	0.23	D-Ppt.	Dp	0.09
Zinc	D	Dp	0.22	D	E	0.14
Nickel	NC	U	0.20	NC	U	0.14
Lead	D	U	0.19	D	U	0.10
Iron	D	U	0.18	MD-Ppt.	U	0.14
Plated Metals						
Tinned iron	NC	E	0.70	L-Ppt.	S	0.24
Galvanized iron	NC	S-E	0.18	D	S	0.14
Alloys						
Solder B	NC	E	2.50	L-Ppt.	E	1.60
Solder A	NC	U	2.50	L-Ppt.	E	1.40
Brass	D	Dp	0.30	D-Ppt.	Dp	0.45
Phosphor bronze	D	S-Dp	0.41	D	S	0.38
Rezistal Steel	NC	U	0.33	D-Ppt.	U	0.26
Type metal	L	E	0.34	L	E	0.24
Duriron	NC	U	0.31	D	U	0.28
Aterite No. 136	L	S	0.22	L	S	0.16
Nickel silver	L	S	0.26	L	S	0.24
Nicolene	L	U	0.28	L	U	0.20
Niaco	NC	U	0.22	D	U	0.20
Monel	NC	U	0.20	Ppt.	U	0.12
Blank	Clear amber color		0.26	Clear deep straw Slight ppt.		0.18

In general, it was found that metals or alloys containing either copper or tin produce excessive fog with developers. The precise action of a copper salt in causing fog is not thoroughly understood—presumably it acts as a catalyst in accelerating the rate of oxidation of the developer, and it is well known that developer oxidation products cause fog. Stannous salts reduce the unexposed silver grains of the emulsion to metallic silver, which constitutes the fog.

Tin and copper or alloys containing these metals should not be used in metallic contact with a more noble metal in the presence of developing or fixing solutions because of electrolytic action. For instance, a lead-lined tank should not be soldered, but should be lead-burned, and the same applies to lead piping—that is, the joints should be "wiped" and not soldered. In the case of metal tanks with joints soldered on the outside, no developer fog was produced.

An acid fixing bath is very corrosive, and as far as is known no metal or alloy has yet been found which under all conditions is resistant to fixing baths. The metal or alloy to be satisfactory should withstand the following tests:

1—It should be free from corrosion after two weeks' contact under tropical conditions with either fresh or exhausted fixing baths.

2—It should not produce undesirable changes in the appearance of the bath, such as (*a*) precipitation of dissolved constituents, (*b*) formation of foam or scum at the surface of the solution, or (*c*) objectional discoloration of the bath.

Any loss in the rate of fixation caused by any of these effects would be sufficient reason for rejection of the material.

Tests made with the four different fixing baths previously described may be summarized as follows:

1—Lead, nickel, Niaco, Monel, type metal, and Rezistal steel are fairly satisfactory. With lead, nickel, brass, and Monel in partially and completely exhausted fixing baths, a layer of silver plates out of the solution on the metals.

2—Copper, iron, tin, tinned iron, Duriron, nickel silver, phosphor bronze, and Solders A and B are attacked to a varying extent. They discolor the bath, and enough precipitation occurs to cause them to be undesirable.

3—Aluminum, zinc, galvanized iron, Aterite No. 136, and Nicolene are very unsatisfactory. All corrode badly, the fixing baths are covered with a thick scum, and heavy precipitates are formed. (The effect of electrolysis on the rate of corrosion of metals and alloys in fixing baths will be dealt with in a future paper.)

Almost all the metals and alloys tested exhibited a vigorous and undesirable reaction with the hypo-alum toning bath. The experiments were conducted for one week at a temperature of 110 to 120° F., or approximately at the temperature at which the bath is recommended for use.

Lead, nickel, and Monel were least affected, but even these metals are not entirely satisfactory with toning baths. Aluminum, copper, zinc, brass, phosphor bronze, and galvanized iron showed visible corrosion.

For toning solutions, glass, porcelain, or enameled apparatus are to be recommended rather than metallic containers.

Of non-metallic materials *glass* is chemically the most satisfactory, but it is fragile and its application to large tanks and trays is limited. *Enameled steel* is extensively used for small trays and tanks, though the vitreous coating is relatively brittle, and an injury to it destroys the usefulness of the vessel. *Impregnated fibrous materials* are in general unsatisfactory though wood impregnated with paraffine is very useful at moderate temperatures. The commonest and best photographic *lacquer for metals* consists of asphalt or a mixture of asphalt and rubber cement, and baked japan is very satisfactory, but neither will resist a strongly alkaline solution. *Porcelain and glazed earthenware* are usually unsatisfactory because of minute cracks which develop; these offer starting points for the growth of crystals which eventually destroys the glaze. *Hard rubber and nitrocellulose* withstand nearly all aqueous photographic solutions except those of oxidizing agents, but they are somewhat brittle and tend to buckle in in hot weather. *Rubber compositions* are in general unsatisfactory, but good quality *rubber sheeting* is used as a tank lining with good results. *Slate* and *alberene stone* are very suitable for large tanks for developing solutions, and the latter may also be used for fixing solutions. *Wood* is the cheapest available material for tanks, and may be used for developing, fixing and washing solutions; the tanks must be well constructed and well braced to prevent warping; they should not be painted, because alkaline developing solutions soften the paint and cause it to flake off.

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VII. Selection of Material for Specific Equipment.

In considering the selection of material for a specific piece of chemical plant apparatus other factors than chemical resistance to the substance handled must be taken into account; but, as was pointed out in Chapter I, this factor of chemical resistance is dominant in most cases, its importance being proportional to the destructiveness of the chemical for which the apparatus is designed. The other factors to be considered may be divided into two groups: physical characteristics and cost. The first includes, for example, mechanical strength, hardness, heat conductivity, melting point, etc. The second includes purchase cost, cost of installation and maintenance (including shutdowns), depreciation, etc., and a number of less tangible factors that may be grouped under the head of convenience. Such a heading would include, for example, the availability of skilled labor for maintenance, the effect of the apparatus on morale and labor turnover, etc.

Of course a strictly logical point of view requires the consideration of cost as a function of the physical and chemical characteristics of the material in question, as well as of other independent variables, but in practical work the classification outlined above is often more convenient and suggestive and therefore more useful.

The difficulty of classifying the destructive reactions discussed in this book has been mentioned in Chapter I. One roughly approximate generalization may be made however, which will be found very useful, if it is realized that it is only approximate; in a given case it may serve as a guide, but the limits within which it is true must be determined by experiment. The generalization is that most substances resistant to acids are attacked by alkalies, and vice versa. A few cases illustrating this are given in the following table.

Resistant to Acids, Attacked by Alkalies	Resistant to Alkalies, Attacked by Acids
Ferro-silicon	Iron
Lead	Copper
Aluminum	Silver
Silica	Cotton
Silk	
Wool	
Phenolic resins	

Selection of Materials for Specific Equipment.

During the past ten years there has been a remarkable increase in the kinds of material from which standard apparatus is constructed. Many of these "freak" constructions have proved impractical; others have won a well-deserved place in standard chemical engineering practice. Pumps of hard-rubber, filter presses of chemical stoneware and evaporators of high silica iron are examples of construction that only a few years ago would have been regarded as eccentric.

Among the newer materials available for apparatus construction are commercially pure iron, high chromium and other alloy steels, ferro silicon alloys, nichrome, Monel metal, and various bronzes, while the field of many of the older construction materials, such as copper, nickel, aluminum, enamelware, stoneware, glass, silica, concrete, wood, hard rubber, and vulcanized fiber has been greatly enlarged.* A very brief survey of the properties of some of these materials is given here by way of summary, since their chemical behavior has been treated in detail in earlier chapters.

Commercially pure iron contains less than approximately 0.16 per cent foreign matter in good samples, and is resistant to mild acid corrosion and rusting. It is useful for structural work in chemical plants and other places where atmospheric conditions are severe.

High chromium and similar *alloy steels*, so-called "stainless steels" vary greatly in their resistance to chemical action. Such steels suitably chosen for the service in view are very resistant to mild acid corrosion and practically immune to rusting. They are used for cutlery and for apparatus parts, as well as in sheet form for the foundation of chemical enameled ware.

High silicon cast iron is resistant to the corrosive action of most acids and is extensively used for large pieces of apparatus such as tanks, sulfonators, nitrators, autoclaves, pipe lines, etc. It is brittle and difficult to machine, but may be accurately ground.

Nichrome is resistant to oxidation at high temperatures as well as to mild acid corrosion; it is widely used in the form of electric wire and in other high temperature work.

Monel metal combines strength and other excellent physical characteristics with resistance to corrosion. It may be machined, forged hot or cold, brazed, soldered or welded. It withstands acid corrosion well and is resistant to neutral or alkaline oxidizing agents, but is attacked by acid oxidizing agents. It is used in the manufacture of machine parts such as gears, pinions, nozzles, agitators, etc., and in the manufacture of metal filter cloth. Since its resistance to corrosion does not depend on a protective coating, it is relatively unaffected by erosion.

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* Penucci, Smith, E. H., Long, Schenck, Thum, Fahrenwald, Aupperle, Schneider, Steffens, Boggess, Milliken, F. Jr., Whittaker, H. F., Blough, McKay, Miner, Bell, Knight, Greene, Marshall, Tyler, Viol, Chem. Met. Eng., *28* (1923), 676; McKay, Balke, Irwin and Ashton, Strickland, Hoover, Ind. Eng. Chem., *15* (1923), 554. Symposiums on materials for industrial equipment.

Copper and bronzes.—The growing use of copper is due to a combination of characteristics; the metal, being extremely easy to fabricate, can be made into any form required, and it combines with that property a considerable degree of chemical resistance. Copper is unattacked by caustic alkalies and by non-oxidizing acids in the absence of air; it is attacked strongly by ammonia and substituted ammonias in the presence of air, as well as by oxidizing acids and other acids in the presence of other oxidizing agents.

Ordinary brasses and bronzes are useful where they are subjected only to mild corrosive action, such as that of sea water or other salt solutions; they resist boiling 10 per cent sodium chloride solutions, and manganese bronze is said to be the best available material for handling 85 per cent formic acid.

Among the bronzes developed especially to withstand corrosion may be mentioned Aterite, a nickel brass, Meco metal, a copper-nickel-zinc alloy, and Ampco, an aluminum bronze containing chiefly copper, aluminum and iron. The manufacturers recommend these alloys for use with superheated steam, hydrofluoric, organic and some concentrations of sulfuric acids, but not for use with chromic, hydrochloric, nitric, mixed or picric acids, nor with ammonium hydroxide.

Aluminum is in a class by itself on account of its lightness. It is very sensitive to the action of strong alkalies, but is resistant to the action of many acids. It is used in acetic acid manufacture, in the food, oil, wax and other industries, and for the manufacture of cooking utensils, and has further miscellaneous uses.

Wood has such multifarious applications that it is impossible to summarize them. Improvements in manufacture have increased the use of wooden pipe lines and fittings, absorption towers, etc.

Chemical stoneware has widened its field markedly in the last few years because of developments in its manufacture. Large sized units and very intricate pieces, such as distributors, condensers, manifolds, nozzles and pumps, are now built and used in a way that would have been impossible in this country before the war. Considerable improvement has also been made in the heat resisting properties of this material.

Glass is the most striking example of the development of a familiar material and its application to new industrial uses. The manufacture of mechanically strong glasses, chiefly of the borosilicate type, with low coefficients of expansion (0.0000032 per degree centigrade at 19-350° C.), is responsible for this, and advantage may now be taken in industrial apparatus of the unique transparency of glass and its great chemical inertness.

The present maximum limits in size have been raised, for example, to 30 liters for pressed dishes, 72 liters for mold-blown flasks, 12 inch diameter for socket pipes and cylinders, and 3 inch diameter of T's, L's, etc., made by lamp working; the accuracy of dimensions has also been increased.

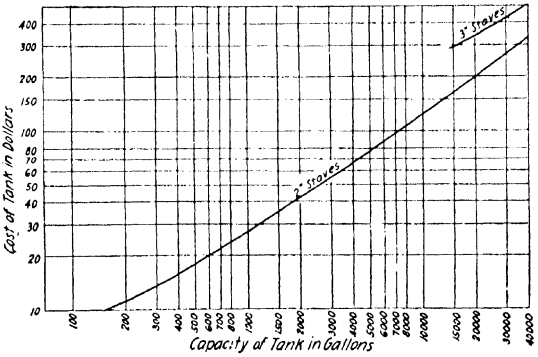
Fused silica ware is also finding increased industrial application because of its resistance to attack by acids and its extremely low coefficient of expansion, 0.00000054 per degree centigrade at 0-1000° C.

For equipment without moving parts and free from extremes of temperature, the range of materials is naturally widest. Tanks, vats, crystallizing pans and pipe lines can be of almost any material that the chemical conditions prevailing may demand. Hydrofluoric acid is being successfully handled in iron tanks and drums, as it quickly coats the metal with a tough integument of iron fluoride which resists further corrosive action. Obviously an iron pump would not be successful for handling hydrofluoric or hydrofluosilicic acid, nor iron fans for air saturated with such vapors.

Storage Systems for Liquids.—In general tanks of wood or steel plate construction are suitable, wooden tanks having the advantage as to the first cost.

Tanks.

Wood.—It is but infrequently that a tank of suitable wood, properly constructed, cannot be made to serve equally as well as one of lead, copper, aluminum or Monel metal. On the other hand, wooden tanks require care in their selection. The writer recently had brought to his attention a serious defect in the product of an electroplating shop due to the use of pine



Courtesy, C. S. Robinson, Mass. Inst. of Technology.

FIG. 20.—Comparative Cost of Tanks.

tanks, the extract from which caused an imperfect deposit. With the substitution of oak tanks the trouble ceased.

Steel Plate.—For outdoor storage for water, oils, solvents, tar, etc., tanks of steel-plate are preferable. They withstand weather conditions better than wooden tanks. The wooden tank sheathed in icicles was a familiar sight in railroad yards and industrial plants up to a few years ago. Well made riveted steel plate tanks are practically leak proof, present almost no maintenance expense except repainting every few years, and are preferable from the fire risk point of view.

Concrete storage tanks are suitable for many liquids, and are dealt with *in extenso* elsewhere in this book. Tanks of acid-proof masonry are used for sulphuric, nitric, hydrochloric and mixed acids. Tanks lined with tile are used for service where the greatest possible cleanliness is an object; as for instance photographic solutions, fruit juices, syrups and stock for fine papers. The supporting structure of these tile tanks may be concrete, brickwork, or steel-plates. Bleaching tanks for paper pulp are frequently of tile set in concrete.

Stoneware and glass storage vessels are limited to comparatively small quantities of highly corrosive liquids, although systems of many (up to 60) separate stoneware vessels, each of from 100 to 1000 gallons capacity have been successfully employed.

Lead-lined tanks are in general use for strong acids, alum liquor, sulphite liquor, etc. The quality of the lead and the skill with which the lining is fitted are both of great importance. The best chemical lead is free from antimony and contains from 0.04 per cent to 0.08 per cent copper, 0.005 per cent to 0.015 per cent silver and less than 0.005 per cent bismuth. Such lead will resist sulphuric acid up to 60° Bé. at all temperatures, and acid up to 96 per cent H_2SO_4 in the cold. Enormous quantities of such lead, fabricated by the art of the lead burner are used in the acid, heavy chemical, fertilizer, oil refining and metallurgical industries. So-called "hard lead" contains about 8 per cent antimony, and is useful for parts of pumps, valves, blowers, etc., but is inferior in acid resisting qualities, especially at high temperatures.

Aluminum tanks have come into more general use in England and on the Continent than in America. Possessing mechanical strength, being resistant to many acids and liquors and having the added advantages of lightness, comparatively low cost and attractive appearance, they often prove extremely useful. Animal and vegetable oils, light varnishes, leather dopes, artificial leather solutions, flavoring and drug extracts, essential oils; acetic, nitric and lactic acids; glycerine, soap solution, oleic acid; vinegar, fruit juices and syrups are among the liquids successfully handled in aluminum tanks.

Monel metal possesses the advantage of high mechanical strength comparing favorably with steel, amenability to the usual methods of fabrication, moderate cost and great resistance to many troublesome corrosives. Monel metal tanks are extensively used for storing and handling dye liquors, bleaching solutions, fruit juices, organic acids, photographic solutions, and many salts in solution, and for pickling acids. Monel is not suitable for nitric acid and strongly oxidizing liquors. Monel is preferable to any other metal or alloy for hydrochloric acid liquors but hard copper lined tanks are preferable if the temperature is below 60° C.

Enameled iron gives almost complete immunity to corrosion from organic and many inorganic acids. The concerns manufacturing this equipment have developed a wide range of enamels suitable for different conditions. They have the disadvantages of high cost and liability to injury from rough handling. Many expensive enameled tanks have been ruined by carelessness in cleaning, removing agitators, etc. Once the enamel is chipped or perforated the tank is ruined for most purposes. Both welded and cast vessels are available in enameled construction. According to E. P. Poste and M. Donauer * "A given enamel may act quite differently with regard to its resistance to different corrosive conditions. Different concentrations of a given acid vary so greatly with respect to action on enamel that a soft enamel may be possible at one concentration and entirely impossible at another.

"In so far as the acid resisting enamel meets all the chemical requirements of the others, this prompts the question why not use that enamel on all equipment and have one standard grade? There are limitations regarding the shape and size of a piece which can be enameled and the limitations are greater with the more acid resisting enamels. The iron vessel must be of fairly simple design with uniform surface to be enameled. For acid conditions the enamel must not only be more resistant but a perfect enamel coating is necessary. This limits the size of pieces to a smaller range and it is more essential to have a simple design. The limitations are gradually being extended or more thoroughly understood and the entire range of enameled apparatus covers interesting possibilities for many lines of industrial and chemical operations."

Enameled tanks are extensively used for fruit juices, photographic solutions, various salts and organic chemicals in solution in fine chemical, dye and drug factories; flavoring and medicinal extracts, serums, dairy products; beverages, etc., and particularly where bacteriological as well as chemical purity is required.

Evaporators and Vacuum Pans.

Materials for use with this class of equipment must be selected with due regard to mechanical properties and thermal efficiency, as well as resistance to chemical action.

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* Ind. Eng. Chem., 15 (1923), 469.

Cast iron for evaporator work must be of high quality, close-grained and perfectly homogeneous. Tubes may be of steel, but charcoal iron or wrought iron is preferable. Apart from iron the shells may be of copper, bronze, brass, Monel metal, malleable nickel, aluminum; lead, tin or silver lined copper or iron, enameled iron or high silica iron. A few evaporators are in use with acid-proof brick and stoneware linings. Tubes may be of copper, brass, bronze, nickel, Monel metal, aluminum or lead, in addition to the many varieties of iron and steel.

In the selection of tube materials it is sometimes expedient to adopt a metal inferior from a chemical point of view if other qualities are superior. For instance nickel has been rejected for the tubes of evaporators for alkaline liquors in certain instances where it showed up best in the chemical tests because of the unreliability of the nickel tubing available as compared with iron. Also it should be taken into consideration whether the deposition of scale or salt and consequent cleaning will be heavy or light, as some tubes withstand constant cleaning better than others.

The following table gives the usual materials for some of the liquids commonly handled in evaporators:

TABLE OF MATERIALS FOR EVAPORATORS

Liquid	Shell	Tubes	Remarks
Caustic soda Caustic potash	Cast iron or steel	Charcoal iron	For caustic soda, copper tubes; also for high concentrations nickel has also been used.
Alum — i.e., aluminum sulphate	Hard lead or lead lined iron	Hard lead or lead lined and covered iron	Alum liquor always contains free H_2SO_4
Salt — i.e., sodium chloride	Cast iron	Copper, brass, Monel metal	
Saltpeter (sodium nitrate)	Cast iron	Charcoal iron	
Sodium phosphate	Cast iron	Steel	
Calcium chloride	Cast iron	Wrought iron	
Epsom salts (magnesium sulphate)	Cast iron	Copper or charcoal iron	Iron preferable as frequent cleaning necessary is hard on copper.
Ammonium nitrate	Cast iron	Aluminum	Enameled iron shells also used.
Iron sulphate	Cast iron	Copper or Monel metal	

TABLE OF MATERIALS FOR EVAPORATORS—(*Continued*)

Liquid	Shell	Tubes	Remarks
Calcium acetate (acetate of lime)	Cast iron	Copper	
Pyroligneous acid (crude acetic)	Copper	Copper	
Soda-pulp liquor	Cast iron	Wrought iron	
Tartaric acid	Hard lead or lead lined iron	Hard lead or lead lined and covered iron	
Sulphite-pulp liquor	Cast iron or steel plate	Wrought iron	The original acid liquor is neutralized in practice prior to concentration, otherwise copper concentrators would be called for.
Textile liquors from mercerizing plants, etc. (alkaline)	Steel	Steel	
Tank-water from packing houses, garbage plants, etc.	Cast iron	Brass, copper, or special bronze	Monel metal and aluminum have also been employed.
Distillery slop	Cast iron	Copper	Brass tubes also have been used.
Glycerine, and spent soap lye	Cast iron or steel plate	Copper	Superheated steam fittings cast steel.
Glue	Cast iron	Copper or brass	
Gelatine	Cast iron	Copper, brass, Monel, nickel	Shells sometimes copper, Monel or aluminum.
Drug extracts, cascara, etc.	Copper	Copper	Also Monel tubes and aluminum and enameled iron.
Acetic acid	Copper and aluminum	Copper	Durability depends on exclusion of air.
Lactic acid	Copper	Copper	
Tanning extracts	Copper	Copper, brass, or bronze	
Maltose (malt syrup)	Cast iron or copper	Copper	
Milk	Copper	Copper	Iron or steel stills used for skim-milk and whey.

TABLE OF MATERIALS FOR EVAPORATORS—(*Continued*)

Liquid	Shell	Tubes	Remarks
Sugar	Cast iron, steel or copper	Wrought iron, steel, or copper	Copper used largely in vacuum pans.
Fruit juices	Copper, enameled steel, or tinned copper	Copper, Monel, nickel, aluminum, tinned copper	
Coffee extract	Copper or Monel	Copper, brass, or Monel	Enameled iron shells also used.
Hexamethylenetetramine	Cast iron or enameled iron	Wrought iron, or enameled iron	Enameled iron necessary for final stages of concentration of high-grade product
Water	Cast iron or steel	Steel, brass, copper or Monel metal	Monel for sea-water and highly alkaline water.

Condensers.

In general the data given above for evaporators will apply equally well to surface condensers, but wherever there is a free choice between copper and any other metal copper is preferable because of its greater efficiency of heat transfer. Also, in using the above data for condensers steel plate can be substituted throughout for cast iron shells when desired.

Pumps.

The selection of proper materials for pumps is highly complicated as the mechanical demands of a complex mechanism, friction of surfaces on each other, bursting strength and torsional qualities have to be taken into consideration as well as the chemical properties. The writer was recently shown by a chemical pump manufacturer an instance where six unsuccessful attempts have been made to fashion a pump impeller from the alloy specified by a works chemist, and insisted on as being the only composition capable of resisting the liquid being pumped. Moreover in practice, liquors will frequently contain sediment and grit which rapidly destroy the softer metals and alloys by erosion and promote corrosion by exposure of new surface on impellers and casings.

There are certain technical terms used by manufacturers of pumps that require some explanation. "*Lined*" pumps are those with cylinders lined with bronze, brass, Monel, wooden staves, stoneware or hard rubber. "*All iron*" pumps have unlined cylinders, bored to size. In such pumps the cylinders are cast and the moving parts forged of steel or malleable iron. "*Bronze*

or brass fitted" pumps have certain parts, usually pistons, rods, impellers, shaft sleeves, wearing rings and valve mechanisms of the special metal specified. As this term is vague and used variously by different pump manufacturers, it is always wise to specify just what material is to be used for each part. Brass piston rods on steam pumps are undesirable because of the poor service of brass under steam cylinder conditions. Where brass or bronze is necessary at the wet end, a complex piston rod can always be furnished with steel at the steam end.

The following is the classification of reciprocating pumps as to materials and manner of fitting for handling various liquids adopted by several of the largest pump manufacturers.

Direct acting pumps, power pumps, and crank and flywheel pumps are classified according to the manner in which the liquid cylinder is fitted, as follows:

Standard Fitted—This means that the pump is fitted with cast iron liquid cylinder, steel piston rod, bronze liner, bronze valve seats, bolts and springs, rubber or bronze valves and cast iron liquid piston or plunger.

Standard Bronze Fitted—This signifies a pump fitted with cast iron liquid cylinder, bronze piston rod, bronze liner, bronze valve seats, bolts and springs, rubber or bronze valves, and cast iron liquid piston or plunger.

Full Bronze Fitted This is a pump which carries a cast iron liquid cylinder, bronze liner, bronze valve seats, bolts and springs, rubber or bronze valves, bronze liquid piston or plunger.

All Iron Fitted—Pumps for handling tar, ammonia, etc., are built without bronze fittings. In this type of pump the liquid cylinder is of cast iron, valve bolts of steel, valve springs of steel, and liquid piston or plunger of cast iron. Iron fitted pumps are furnished with, or without, cast iron liners, depending on the size of the pump.

All Bronze—This is a pump with a liquid cylinder of bronze, bronze liner, bronze piston rod, bronze valve seats, bolts and springs, bronze valves and bronze water piston or plunger.

In the above classifications the term "Standard Fitted" generally applies to duplex pumps only. Simplex Pumps are built regularly "Standard Bronze Fitted."

For centrifugal pumps the conditions are similar, it usually being sufficient to specify simply the materials of the impeller and the casing, and in chemical work these are usually the same.

In the compilation of the foregoing tables of materials for pumps, in general the materials have been mentioned in order of their suitability and practicability. The materials mentioned are what might be called those of "minimum resistance" i. e. there could be chosen in many instances other materials of unnecessarily great resistance. For instance, stoneware pumps could be specified as far as chemical resistance is concerned for practically all the liquids mentioned, but have only been specified in the tables when no metal pump would give service.

TABLE OF MATERIALS FOR CENTRIFUGAL PUMPS

Liquid	Materials	Remarks
Acetic acid, conc.	Phosphor bronze, hard lead, Monel lead or aluminum	
Acetic acid, dil.	Hard rubber, bronze, Aterite, Monel metal, or enameled iron	
Alkaline brines	All iron	
Alcohol (crude)	White bronze, brass, Monel metal	
Alum solution	Hard lead or bronze	Contains free H_2SO_4.
Ammonia, aqua	All iron	
Aniline	All iron	
Benzene	All iron	
Beer and beer wort	Bronze	
Beet juice	Monel metal or brass	
Brine (calcium)	All iron, Duriron	
Brine (sodium)	Bronze or Monel metal	
Blood	Bronze, Monel metal or aluminum	
Cane juice	Bronze or brass	
Caustic soda	All iron	
Caustic potash	All iron	
Chlorine in solution	Hard rubber, enameled iron, stoneware	Enameled pumps are fragile.
Chloride of lime	Hard rubber, Monel metal or enameled iron	
Chloride of zinc	All iron or Monel metal	
Citric acid	Bronze, Monel metal, aluminum, hard lead, hard rubber	
Coal tar oils	All iron	
Carbon bisulphide	Iron or bronze	Metal must not contain lead.
Copper sulphate	Bronze or Monel metal	
Creosote oils	All iron	
Cyanide liquors	Duriron, all iron, or stoneware	No alloy will permanently resist cyanide.
Distillery slop	Bronze or Monel metal	
Ethyl acetate	Bronze free from lead or zinc	
Ethyl chloride	Bronze, no alloys containing lead or zinc	
Ethyl iodide	Hard lead	
Ethyl phthalate	Bronze free from lead or zinc	
Ethyl sulphate	Hard lead	
Fatty acid liquors and melted fats	All bronze, Monel metal and aluminum	
Ferrous chloride	Hard rubber, Duriron	
Ferrous sulphate	All iron	
Ferric chloride	Stoneware	Duriron if cold.

TABLE OF MATERIALS FOR CENTRIFUGAL PUMPS—*Continued*

Liquid	Materials	Remarks
Gasoline	Iron, bronze fitted	
Glycerine, pure	Bronze	
Glycerine, liquors	Aluminum, Monel metal or bronze	
Hydrochloric acid, conc.	Stoneware, hard rubber	
Hydrochloric acid, dil.	High silica iron, Monel metal or hard rubber	
Linseed oil	All iron	
Lye, caustic	All iron	
Magnesium chloride (caustic)	Hard lead	
Milk	Bronze, Monel metal or enameled iron	Special construction to permit frequent cleaning.
Molasses	Bronze or Monel metal	
Nickel salts in solution	Pure copper	
Nitric acid, conc.	High silica iron, lead	Also stoneware armored with iron.
Nitric acid, dil.	High silica iron, hard rubber, aluminum	
Oil, vegetable, in general	All iron	
Petroleum	All iron	
Potash liquors	All iron	Duriron if conc.
Potassium nitrate (caustic potash niter)	All iron	Duriron if conc.
Pyroligneous acid	Duriron	
Rape-seed oil (colza oil)	Iron, bronze-fitted	
Sea water	Monel metal, bronze or brass	
Sewage	Brass, bronze or Monel metal	
Soap, liquors	All iron	
Sodium carbonate	All iron	
Sodium hyposulphite	Lead-lined iron, hard lead	
Sodium chloride	Bronze or Monel metal	
Sodium peroxide	Stoneware	
Sulfite, acid (pulp mill)	Hard lead, phosphor bronze	
Sulfur chloride	Iron (painted with oil)	Oil forms with the sulphur chloride a tough film which protects the metal.
Sulfuric acid, dil.	Hard lead, lead-lined iron or high silica iron. Very dilute: hard rubber, bronze and Monel metal	
Sulfuric acid, conc.	High silica iron, grey iron, stoneware	

TABLE OF MATERIALS FOR CENTRIFUGAL PUMPS—*Continued*

Liquid	Materials	Remarks
Sulfurous acid, conc.....	Phosphor bronze, Monel metal, enameled iron	Also stoneware.
Sulfurous acid, dil.......	Bronze	
Tanning liquor	Bronze, brass or Monel metal (no iron)	
Tar	All iron	
Tin chloride	Duriron, hard rubber, Monel metal	
Vinegar	Hard rubber, Monel metal, aluminum	Also tin-lined bronze or iron.
Wood pulp (paper stock)	Bronze or Monel metal	All iron if stock is neutral or alkaline.
Zinc chloride	Monel metal, high silica iron	

TABLE OF MATERIALS FOR RECIPROCATING PUMPS

Liquid	Material	Valves	Packing
Acetic acid, conc.	Hard rubber, Duriron, phosphor bronze	Bronze disc	Hydraulic
Acetic acid, dil.	Hard rubber, Monel metal, Duriron, phosphor, bronze	Bronze disc	Hydraulic
Alkaline liquors	All iron	Iron disc	Hydraulic
Alcohol (crude)	Bronze, Monel metal	Monel disc	Hemp
Alum (contains H_2SO_4)	Duriron, cast iron	Iron disc	Asbestos
Ammonia, aqua; Ammonium hydroxide	Duriron, cast iron	Iron disc	Hydraulic
Aniline water	All iron	Iron disc	Hydraulic
Benzene	All iron	Iron disc	Hemp
Beer .	Phosphor bronze	Bronze disc	Hydraulic
Beet juice	Monel metal or bronze	Monel or iron disc	Hydraulic
Brine (calcium)	Duriron, Monel metal	Monel or bronze disc or rubber	Hydraulic
Brine (sodium)	All iron, Monel metal	Bronze or rubber	Hydraulic
Blood	Bronze, Monel metal or aluminum	Redmanol composition ball	Bronze ring

TABLE OF MATERIALS FOR RECIPROCATING PUMPS
(*Continued*)

Liquid	Material	Valves	Packing
Cane juice	Iron, Monel metal, or bronze fitted	Monel or bronze disc	Hydraulic
Carbon tetrachloride	Duriron	Iron disc	Asbestos
Caustic soda	Iron	Iron disc	Asbestos or hemp
Caustic potash	Iron	Iron disc	Asbestos or hemp
Chlorine water	Hard rubber or stoneware	Rubber	Asbestos graphitized
Coal tar oils	All iron	Iron disc	Iron ring
Creosote oils	All iron	Iron disc	Iron ring
Cyanide liquors	Duriron	Iron disc	Hemp
Distilling slop	Bronze or Monel metal	Bronze disc	Hemp
Ferrous chloride	Duriron or iron	Iron disc	Hemp
Ferric chloride (cold)	Duriron	Iron disc	Asbestos
Ferric chloride (hot)	Stoneware	Asbestos composition	Asbestos
Gasoline	Bronze fitted	Bronze disc	Hemp
Glue (hot)	Bronze or aluminum	Bronze ball	Bronze ring
Glycerine (also spent soap lye)	Bronze or Monel metal	Bronze disc	Bronze ring
Greases (hot)	Bronze fitted	Bronze disc	Bronze ring
Hydrochloric acid, dil.	Hard rubber, Monel metal	Monel disc or rubber	Bronze or Monel covered asbestos
Hydrochloric acid, conc.	Stoneware	Asbestos - resin composition	Asbestos or wool soaked in paraffin
Lactic acid	Duriron	Monel disc	Monel covered cork or asbestos
Lime, milk of	Iron or Monel metal	Iron or Monel disc	Hemp
Linseed oil	Bronze fitted	Bronze disc	Hemp
Lye, caustic	All iron	Iron disc	Iron ring
Magnesium chloride (hot)	Duriron or iron	Iron disc	Asbestos
Milk	Monel metal or bronze	Bronze clapper or disc	Solid piston
Mineral oils	Bronze fitted	Bronze disc	Bronze ring
Molasses	Bronze or Monel fitted	Bronze or Monel ball	Bronze ring
Naphtha (solvent)	Bronze fitted	Bronze disc	Bronze ring
Nitric acid, conc.	Duriron or lead	Hard lead	Asbestos
Nitric acid, dil.	Iron, Duriron, or aluminum	Iron disc	Hemp

TABLE OF MATERIALS FOR RECIPROCATING PUMPS—(*Continued*)

Liquid	Material	Valves	Packing
Oils, vegetable	Bronze fitted	Bronze disc	Bronze ring
Paraffin, melted	Bronze fitted	Bronze ball	Bronze ring
Petroleum	Iron	Iron ball	Iron ring
Potash brines	All iron	Iron disc	Hemp
Pulp (containing acid)	Phosphor bronze	Bronze ball	Hemp
Rape-seed oil (colza)	Bronze fitted	Bronze disc	Bronze ring
Rosin, melted	Iron or Duriron	Iron disc	Iron ring
Salt water	Bronze fitted	Rubber	Hydraulic
Sea water	Bronze or Monel fitted	Rubber	Hydraulic
Sewage	Bronze fitted	Bronze disc	Hydraulic
Syrups	Bronze fitted	Bronze disc	Bronze ring
Soap	All iron	Iron disc	Hemp
Sodium chloride (strong)	All iron or Monel metal	Bronze disc	Hydraulic
Sodium carbonate	All iron	Iron disc	Hydraulic
Sodium hyposulphite	Lead-lined iron	Rubber	Asbestos
Strontia, caustic	All iron	Iron disc	Iron ring
Sulfuric acid, conc.	Duriron or iron	Iron disc	Asbestos
Sulfuric acid, dil.	Lead, Monel metal, or Duriron	Bronze disc	Asbestos
Sulfuric acid, very dil.	Bronze or hard rubber	Bronze or rubber disc	Hemp
Sulfurous acid	Phosphor bronze	Bronze disc	Bronze ring
Sulfite acid (pulp mill)	Phosphor bronze	Bronze disc	Bronze ring
Tar	Iron	Iron ball	Iron ring
Tannic acid	Bronze or brass	Brass disc	Brass ring
Tanning extracts	All bronze, brass, Monel metal	Bronze disc	Hemp
Tank water (packing-house)	Bronze fitted	Phenol-formaldehyde resin (Redmanol) composition ball	Bronze ring
Tin tetrachloride	Duriron, hard rubber	Rubber	Asbestos
Toluol	Bronze fitted	Bronze disc	Hemp or metal-covered cork or asbestos
Turpentine	Iron	Iron disc	Iron ring
Vegetable oils in general	Iron	Iron disc	Iron ring
Vinegar	Hard rubber, aluminum, Monel metal	Bronze disc or rubber	Hemp

TABLE OF MATERIALS FOR RECIPROCATING PUMPS—(*Continued*)

Liquid	Material	Valves	Packing
Water	Bronze fitted	Bronze disc or rubber	Hydraulic
Water, containing tar and ammonia	All iron	Iron disc	Iron ring
Water, mine or other acidulous water	Lead, bronze or Monel metal	Bronze disc, or Monel	Hydraulic
Wine	White bronze	Bronze disc	Bronze ring
Wood alcohol	Bronze fitted or brass	Bronze disc or rubber	Hemp
Yeast	Brass fitted	Brass ball	Tin or aluminum
Zinc chloride	All iron	Iron disc	Asbestos or hemp

Valves.

The data contained in the table of materials for reciprocating pumps can be applied very generally to the specifications of valves for handling various liquids. However, it might be noted that stoneware valves and cocks can frequently be employed, yielding perfect immunity from corrosion, where some less resistant material would naturally be chosen for a pump on account of its greater suitability from a mechanical point of view.

The following is a general survey of the varieties of usefulness in industrial chemical work of the different materials from which valves are mainly fabricated.

Iron and Steel Valves.

Chemicals, etc.—Sulfuric acid and mixed acid, used for nitration in the production of explosives, dyestuffs, pharmaceuticals, celluloid and other products, are almost exclusively conveyed in iron pipes fitted with steel valves. For alkalies, iron and steel are the most used materials.

Oils, animal, vegetable and mineral; industrial alcohol; naphtha and other solvents; bleach liquor; many dye liquors; paper pulp; soap lyes; sugar liquors; and a great variety of process and waste liquors in all chemical industries can be handled successfully with iron and steel valves.

Steam.—One of the principal uses of valves in industrial chemical plants is on steam lines. On these lines cast-iron valves are extensively used. Superheated steam, which is extensively used in many chemical processes requires cast or forged steel or Monel metal valves and fittings.

On lines for conveying vapors and gases, which assume very large proportions in petroleum refineries, by-product coke ovens, coal gas plants, water gas plants, wood distillation plants, etc., iron valves are ordinarily used, especially in the form of large gate valves.

Ammonia.—Semi-steel valves and fittings are used to a very large extent on ammonia lines in connection with refrigerating equipment. For valves on all brine lines, steel, malleable iron or semi-steel is very suitable.

Hydraulic Pressure.—For hydraulic presses and accumulators and other high pressure lines such as are used in plants manufacturing vegetable oils, plastics, phonograph records, naphthalene, and a great many other products, steel valves and fittings of high tensile strength are usually used.

Low-pressure Water.—On water lines standard iron body brass fitted, or all iron valves are usually specified.

Compressed Air.—On air lines iron and steel valves are perfectly satisfactory in the majority of cases. This holds equally true of vacuum lines.

Copper and Brass Valves.

Copper in its pure form is used very little for valves and fittings in the chemical industries except in the case of acetic acid. Copper, alloyed with other metals to form brasses and bronzes, is, however, very extensively used for conveying dilute acids, metallurgical solutions, tanning liquors, dyewood extracts, alcohol, ether, solvents, oils, etc.

Monel Metal Valves.

Monel metal valves and fittings have proven very useful for handling many organic acids for alkaline solutions, tin chlorides, hydrogen peroxide, dye liquors, sugar liquors and a great variety of other solutions. For handling solutions of common salt and also many other salts, Monel metal can be used in many cases with much greater satisfaction than any other metal. Monel metal valves are also excellent for super-heated steam.

Lead-lined Iron Valves.

Lead-lined iron valves are used to a very large extent for handling nitric acid and sulfuric acid when it is sufficiently dilute to attack iron. Lead-lined iron valves have to a very large extent replaced lead valves as they combine the acid-resisting properties of lead with the mechanical strength of iron.

Hard-lead Valves.

Hard-lead valves and fittings can be used for any of the purposes mentioned above for which lead-lined iron is suitable, where great mechanical strength is not necessary. For such purposes, valves made of lead alloyed with antimony give very satisfactory service.

Aluminum Valves.

Aluminum has been found useful for acetic acid, dilute solutions of nitric acid and sulfuric acid, oils, fats, greases, linseed oil, stearine, oleic acid, etc. It is also extensively used in the foodstuff and beverage industries, in ammonia concentrators, and in the manufacture of soap and glycerine. Aluminum valves and fittings cannot be used in any case where alkalis have to be handled.

Wooden Valves.

For handling weak acid solutions, metallurgical leaching solutions, tanning liquors, dyewood extracts, etc., wood fittings are used to some extent. Great advances have been made in the construction of pipe and fittings from wood and also in the lining of iron pipe with wood, and for many purposes it will probably continue to be used in spite of the many difficulties presented. For handling hydrochloric acid wood can only be replaced by stoneware and hard rubber.

Hard-rubber Valves.

Hard-rubber valves and fittings are being used more and more in industrial, chemical operations to handle hydrochloric acid and other chlorine liquids which attack all the ordinary materials of construction. Hard rubber is almost the only material which will successfully resist hydrochloric acid out of which valves and fittings can be fashioned. Recently, great advances have been made in the production of large size equipment and it will probably be used in increasing quantities. Hard rubber is also excellent for acetic acid, bleach liquors, dye liquors, vinegar, etc., but can only be used at low temperatures.

Stoneware Valves.

Stoneware is a very large item in chemical construction, although high-silica irons, such as Duriron, Bufflokast, Corrosion, etc., have to a very large extent taken the place of stoneware. However, in spite of the great risk of breakage, and other attendant difficulties, stoneware valves, pipe and fittings are still used in large quantities, especially in the condensation of vapors, during the manufacture of nitric acid.

High-silicon Iron Valves.

High-silicon irons (such as Duriron) are excellent materials for valves and cocks for handling sulfuric, nitric, acetic, phosphoric, oxalic, picric, pyrogallic, benzoic, butyric, formic, hydrocyanic, lactic, tartaric, arsenic, boric and pyroligneous acids; alum (aluminum sulfate), ammonium chloride, ammonium carbonate, ferrous sulfate, copper sulfate, ferric chloride (cold), ammonia, calcium chloride, carbon tetrachloride, tin chloride and zinc chloride. Such material is not suitable for chlorine, hydrochloric acid, hydrofluoric acid, hydrofluosilicic acid, bromine, strong solutions of bromides, hot solutions of ferric chloride, sulfur chloride nor strongly alkaline solutions and only moderately successful for strong cyanide liquors.

Laboratory Table Tops.

Investigations of the chemical behavior of the materials available for laboratory table tops furnish data of value not only for the purpose in view but for other possible industrial uses of these materials. The following tables, made available through the courtesy of the author,* give the results of a series of tests on a number of table top materials; on the basis of these results the materials are given grades on various counts, and they are also graded in the second table on the basis of first cost and maintenance. The discussion of the results is given in the author's own words.

COMPARISON ON COST BASIS OF VARIOUS LABORATORY TABLE TOP MATERIALS

Variety of Wood	Treatment	Action of Acids and Alkali	Action of Water	Action of Non-aqueous Solvents	Combustibility	Surface Condition	Cost of Installation	Rating Possible Total 700	Order of Superiority
Beech...	Plain	68	59	82	38	35	145	427	3
	Aniline black..	71	70	81	35	75	110	442	
Birch....	Plain	70	61	87	42	38	150	448	1
	Aniline black..	77	72	92	38	79	115	473	
Maple...	Plain	71	55	88	41	40	155	450	2
	Aniline black..	75	64	84	35	79	120	457	
Oak.....	Plain	70	46	82	38	29	163	428	4
	Aniline black..	73	59	79	33	63	128	425	

Discussion of Results.†

Alberene ranks slightly higher than any other material tested. It is chiefly deficient in thermal conductivity and apparatus breakage. That the per cent breakage was not higher is due chiefly to the strength of modern laboratory glass. Alberene discolors considerably in organic laboratories and asphaltum diluted with petroleum ether has been recommended to mask stains produced in this type of laboratory. Benzene appears to serve equally well as a diluent. Carbon black in turpentine or pinene also serves well for the purpose. It was found that a mixture of paraffin and finely divided graphite, preferably the Acheson preparation, diluted with several parts of ordinary paraffin thoroughly heated on Alberene and well rubbed after cooling and repeating gives

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* Private communication, Prof. C. R. Hoover, Wesleyan University, Middletown, Conn.

† *Ibid.*

COMPARATIVE EFFICIENCY OF LABORATORY TABLE TOP MATERIALS

Test No.	1	2	3	4	5	6	7		9	10	
Material	Corrosion	Water	Non-Aqueous Solvents	Combustibility	Thermal Conductivity	Surface Effects	Apparatus Breakage	Experimental Rating Basis 700	Cost of Maintenance	Cost of Installation Basis 200	Final Rating Basis 1000
Alberene	99	99	95	100	82	91	89	655	90	100	845
Alberene + paraffin and graphite	99	99	96	98	82 *	90	89 *	653	90	95	838
Asbestos wood ("Transite")	91	78	90	95	92	89	97	632	75	120	827
Asbestos wood + paraffin and graphite	95	83	85	98	92 *	90	97 *	640	78	115	833
"Ebony" asbestos wood	94	92	88	90	90	85	96	635	80	30	745
Bakelite, brown	89	95	97	20	94	75	97	567	50	0	617
Chemical stoneware	100	100	99	100	86	60	82	627	90	0	717
Concrete	67	77	85	98	80	35	83	522	50	165	737
Enamelled iron	99	100	98	100	64	73	86	620	85	0	705
Linoleum	77	78	50	20	100	68	100	493	55	177	725
Marble	77	89	94	90	80	71	87	508	75	65	708
Rubber flooring (Stedman)	86	96	88	40	98	81	100	589	75	120	784
Slate	97	91	93	95	70	45	87	578	70	115	763
Tile, unglazed	99	99	98	100	76	74	88	634	70	65	769
Wood, birch (standard aniline black)	77	72	92	38	96	79	98	552	65	115	732
Wood, birch (modified black)	79	76	90	45	96 *	78	98 *	562	65	115	742

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* Estimated.

a coating of great chemical resistance and equal masking power. This treatment also tends to lessen the pitting which is marked with some samples of Alberene. Unglazed tile and asbestos wood rank next in the experimental summary. The standing of the former is somewhat lowered by the breakage of the only samples obtainable under the heat test. The chief objection to tile is the difficulty of securing proper installation.

Asbestos wood shows a remarkably high score in both summaries, partly because, being stronger than Alberene and other materials, it can be used in thinner sheets, thus lowering its first cost. Impregnated with paraffin and graphite as described in the preceding paragraph, its chemical resistance is slightly increased and its discoloration masked.

Ebony wood is an excellent material if physical strength and insulation resistance are desired. Blisters and extruded matter make it objectionable if subjected to elevated temperatures, and the rather high first cost lowers its rating.

If chemical stoneware could be prepared with a plane surface at reasonable cost, it would be an excellent material for many purposes.

Enamelled cast iron is another material which would probably have a future as a table top material if it could be produced at a reasonable cost.

Concrete and linoleum rate rather low but considering cost and low replacement expense they offer interesting possibilities combined.

Rubber flooring which is now obtainable in large sheets is another material which could be combined with wood or concrete to form a top upon which it would be a pleasure to work.

In conclusion, it is the opinion of the author that on account of lower first cost, for special purposes or if carefully used, wood, rubber, and similar materials are acceptable, but for ordinary purposes refractory monolithic materials of low maintenance cost are the most satisfactory. More attention can well be paid to decreasing the fire risk in chemical laboratories. This end will be secured by using materials which are rated highly on this count in this investigation. The conclusions reached seem to be supported by the practice in recent laboratory construction. In twenty-five new laboratories in the Eastern and Central part of this country about 75 per cent of the desk tops are Alberene, 10 per cent tile, 10 per cent wood, and 5 per cent other materials.

It is unfortunate that one of the most satisfactory materials for laboratory table tops, sheet lead, was not considered by Hoover. It would be interesting to learn its rating on the above basis. The reason for the omission is probably that sheet lead has hitherto been used for this purpose in works laboratories only.

VIII. Concrete.

In view of its enormously increased use for all purposes, it is not at all strange that the chemical engineer should have turned his attention to concrete for a possible material for the construction of tanks and other chemical equipment.

For water storage tanks, settling basins and sumps for effluents, and bins for the storage of solid materials, few new problems arise in the chemical industries that have not been met and solved elsewhere in the engineering field. But with the application of concrete to tanks for storage of oils, solvents, acids, alkalis, paints, vinegar, wine, leaching solutions, photographic solutions, soap liquors, brines, etc., it became necessary to deal with concrete as a specific problem in chemical engineering. This problem has resolved itself largely into a problem of coatings, for uncoated concrete is applicable to relatively few chemical engineering purposes.

In addition to the storage tanks mentioned above, concrete has been employed with success for the following chemical engineering purposes: agitators in pulp mills, vegetable oil refining plants and metallurgical leaching plants; beaters in pulp mills; bleaching equipment in the pulp, paper and textile fields; baking ovens; condensers and coolers for various vapors; coolers for sulfurous gases in the pulp industry; cooling ponds and towers; gas scrubbing towers; gas purifying boxes; generators for hydrogen sulfide in a metallurgical plant; leaching vats for dye, tanning and pharmaceutical extracts and for metallurgical operations; tanning pits and vats; vinegar manufacturing equipment; varnish filtering tanks; water purifying and softening installations; yeast plant equipment. Also quite generally for floors in plants throughout the chemical industries, for which service it is very useful when properly surfaced; and for general building work, such as supports and foundations for equipment.

Maximilian Toch[1] outlines the possibilities of concrete as a chemical engineering material. When Portland cement is mixed with water it generates lime. The lime forms a glutinant material which binds the particles together. Lime is slightly soluble in plain water and is relatively more soluble in salt water. This accounts for the disintegration of Portland cement at the seashore. Any acid, no matter how weak, forms a chemical combination with lime; when the lime in Portland cement is attacked the structure crumbles. Factory floorings made only of Portland cement and sand must be treated to prevent wear. Oil drippings from motors and machinery have disintegrated concrete floorings. Such floors of vinegar tanks have been heavily attacked by acetic acid. Unprotected concrete foundations in chemical plants are destroyed by acid and alkali drippings. Similar foundations of factory buildings are destroyed on waterfronts where niter cake and sludge acids are discharged into the stream. Atmosphere content and climatic changes greatly influence the corrosion of concrete. Instances are cited of Egyptian masonry constructions which have stood in Egypt for twenty centuries but have rapidly disintegrated when re-erected in New York City. The explanation offered is climatic changes and sulfuric acid content of atmosphere.

There are a number of methods used for the preservation of Portland cement but no single method is applicable in every case. The following waterproofing methods are given:

(1) The integral type which is used in the form of dry powder, its action being to densify the concrete, give it colloidal properties and lubricate the mass while pouring. There are a large number of aqueous pastes on the market. Such soaps are to be avoided.

(2) The varnish type which depends for its action on acid resins. It has proved itself waterproof, oil-proof and wear-proof.

(3) The fluo-silicate type which in conjunction with the acid resin type or the bituminous coating type, where a proper bond can be effected, has given most excellent results.

The best protective methods are stated to be as follows:

(1) The membrane method which consists of applying tar, asphalt or other bituminous materials, in conjunction with a membrane such as felt, burlap or textile fabric of any kind.

(2) The brush application on the exterior of a concrete construction of hydrocarbon material which is neutral.

(3) The brush application of an acid resin which combines with the lime of the concrete and forms an integral material on the surface.

(4) The addition of a dry powder, not to exceed 2 per cent, to densify the concrete and make it waterproof.

(5) The addition of an integral powder to the concrete to make it acid and alkali proof.

(6) The application of the brush coating or spray of silicofluoride, which precipitates silica into the interstices or pores of the concrete and makes it proof against oil and water.

(7) Coating the concrete structure with two solutions which interact and precipitate and form an insoluble residue which prevents penetration of chemical compounds.

The success of concrete for storage tanks for oils is dependent on proper design and great care in the selection and mixing of the materials. It is not within the scope of this book to deal with the design of such tanks, but numerous articles on the subject will be found in the files of "Engineering and Contracting," and other technical publications.

Of the selection of the materials and their proper compounding, we will treat briefly. According to C. W. Van Dyke, the best formula for concrete for oil storage tanks is 1 : 1½ : 3. This is in agreement with the findings of the U. S. Bureau of Standards who also found that the next best formulas were 1 : ⅔ : 1⅓ and 1 :2 :4.

Good sand is essential. By this is meant natural sand, or screenings from hard, durable, tough, crushed rock, or gravel, composed of quartz grains. Such sand when dry should pass a screen having 4 meshes to the linear inch; not more than 25 per cent should pass a screen having 50 meshes per linear inch; and not more than 5 per cent should pass a screen having 100 meshes per linear inch. The sand should be absolutely free from organic matter, which is very objectionable in concrete for oil storage purposes. A simple test for organic matter can be made by placing about 2 inches of the sand in a test tube and filling the tube two-thirds full with 3 per cent caustic soda solution. After agitation, the test is allowed to stand 24 hours. If the supernatent liquid is lighter than straw color, the sand is satisfactory for use, but if it is dark in color, the sand should be rejected, or thoroughly washed to free it from organic impurity.

Clay or loam should never be more than 3 per cent by weight. This can be determined by agitating a given volume weight of the sand with water, pouring off the supernatant liquid, repeating this operation three times and evaporating the thus obtained wash water to dryness and weighing.

Pebbles for the coarse material should grade from one inch down to not more than 5 per cent passing through a screen having 4 meshes per linear inch. Pebbles larger than one inch are objectionable because they will not work in well around the reinforcings.

In this kind of work, as in all other concrete construction, the proper proportion of water is of the greatest importance. Particular attention should be given to this, especially in construction around chemical plants where the work is being done by unskilled labor, not specially experienced in concrete construction. The general tendency at all times is to use far too much water.

It should be impressed on those in charge of the work that the use of excessive water is equivalent to decreasing the proportion of cement. According to tests carried out by the U. S. Government, the following table gives the effect of varying proportions of water on the strength of 1 : 1¼ : 3 concrete, the mixing time being one minute:

Gallons of Water per 1 Bag Mix.	Compressive Strength After 28 Days. Pounds per sq. in.
5.75	2.700
6.25	2.400
7.0	1.950
8.0	1.470
10.0	830
15.0	200

The best results are achieved if the mixing time is two minutes rather than one minute. As speed is not usually a matter of great importance in the construction of concrete storage tanks, it is often possible to mix for two minutes instead of one, which yields an increase in strength of 10 per cent, and (which is more important) adds to the density.

The proper curing of the concrete is of the greatest importance when the tanks are to be used for storing oil or other liquids. There are two standard methods:

The first method is to fill the tank with water 24 hours after the concrete is in place and allow it to stand for one month, or longer, if possible.

The second method is to coat the floor and interior walls and roof with three or four coats of 1 : 4 solution of 40° Be. sodium silicate, and to finish with one coat of 1 : 2 solution of 40° Be. sodium silicate.

The protective coating thus formed does not last more than a year, but it serves the purpose of protecting the concrete itself until it has through age become impervious to oil. Tanks thus coated should invariably be aged one month before they are filled with oil.

The German Concrete Association carried out a lengthy series of investigations on the finishing of concrete tanks for oil storage, and their results in the main confirm American practice as outlined above. They found that vegetable and animal oils were much more destructive to concrete than mineral oils. They established three fundamental requirements for linings of concrete oil storage tanks: (1) Such linings should resist penetration by oil and the chemical action of fatty acids. (2) They should be waterproof. (3) They should be unaffected by the oil to be stored when heated to its boiling point. They condemned all coatings containing asphalt and similar substances, because of their solubility in oil. They found sodium silicate to be much better. As the best possible material they recommend "Margalite," a phenol formaldehyde resin paint which was absolutely not affected by any of the oils tried. Exactly similar synthetic resin paints are now on the market in the United States, and have been used with considerable success for resisting not only oils, but acids, alkalies and many saline solutions.

The influence of temperature on concrete tanks for storage or process purposes is very marked and should be carefully taken into consideration in designing such equipment. It is not true, as has sometimes been stated by chemical engineers, that concrete cannot be used for liquids at high temperatures, though it is true that the strength of the material is frequently decreased at high temperature and that this factor has to be taken into consideration in the initial design. According to tests conducted by W. J. Schlick [3] at the Iowa State College, boiling water reduces the strength of concrete, regardless of its age. Numerous slabs of concrete prepared according to various formulas, and all of different ages, were immersed for varying periods in boiling water, and in every case a marked decrease in strength was noted. However, this is not merely a temperature effect, because the same series of experiments showed that oven drying (up to 180° C.) although it caused a slight decrease in strength, did not produce any effect comparable to that caused by immersion in boiling water.

The generally accepted explanation of this phenomenon is that when concrete is immersed in boiling water there is a rapid hydration of portions of the mass which had failed to hydrate previously. This causes changes in volume and a consequent breaking down of the internal structure of the mass.

There are few comparative data on the resistance of concrete to various oils, the most important results being those obtained by the U. S. Bureau of Standards [1] of which the following is a summary:

> Series I consisted of eighteen 1 : 2 : 4 concrete tanks in which were stored eleven mineral oils with gravities varying from 0.742 to 0.959—i. e. from commercial gasoline to a very viscous residuum oil; five vegetable oils and two animal oils. In each tank were placed three 6-inch x 12-inch concrete cylinders to be broken after exposure to the various oils. Quantitative tests were abandoned. After a year's exposure, all were found to be unaffected, except those in cocoanut and lard oil. The surfaces of both of these were attacked and roughened; the cocoanut oil proving more severe than the lard.
>
> Series II and III: Quantitative and Qualitative tests on 1 : ⅔ : 1⅓ concrete tanks. Series II were conducted under no head; Series III were conducted under a 25 foot head. The oils used in these cases were vegetable and animal, the latter varying from s.g. 0.649-0.970. The losses were greater the lower the specific gravity. The head of oil had no appreciable effect.

Tanks containing boiled and raw linseed oil gave noticeable deposit of lime soap. The general result is that the 1 : 1½ : 3 concrete tanks when properly constructed are practically impervious to oils of 0.875 specific gravity (30° Bé.) or heavier.

One of the larger chemical companies (private communication to one of the authors) conducted similar tests of one year's duration with solvent naphtha, acetone, crude methyl alcohol, ethyl alcohol, carbon bisulphide and ether. None of those liquids affect the concrete but there was a heavy loss of carbon bisulphide, a considerable loss of solvent naphtha, ethyl alcohol and ether and almost no loss of acetone and methyl alcohol. The tank containing the acetone was found covered with a resinous "paint" or film at the end of the year.

The most thorough investigation of the action of various chemical agents on concrete is that by M. Jacobson and J. G. De Keravenaut,[5] of which the following is an abstract:

> (1) *Action of acids.*—As a general rule concrete is attacked by acids, the lime of the cement combining to form the corresponding calcium salt. The more active and concentrated the acid, the more vigorous the action. Carbonic acid is not harmful unless the concrete is exposed continuously to high concentrations, as in the case of fermentation industries.
>
> (2) *Action of acid compounds.*—Acid salts such as acid sulfates of sodium, calcium and magnesium act like weak acids. The same applies to acid mineral waters. All these have a slow action on concrete not usually severe enough to preclude its use.
>
> (3) *Action of alkalies and salts.*—The alkalies, potash, soda and ammonia are without action on concrete and the effect of alkaline salts is very variable. Thus: alkaline carbonates accelerate the setting. Concrete is attacked by magnesium chloride and sulfurous salts.
>
> (4) *Action of tar derivatives.*—Generally tar derivatives are without action on concrete, and a certain member of these derivatives are even used up to 1 to 2 per cent in weight to increase the impermeability of the cement to moisture.
>
> (5) *Action of fertilizers.*—Lean concrete (small portions of cement) when freshly laid or when low quality cement is used is attacked by organic fertilizers; but good quality concrete, at least one month old, is not attacked.
>
> (6) *Action of oils and fats.*—Oils and fats, especially lard, wool, olive, whale and tallow oils, attack freshly laid concrete, but when the concrete is more than a month old it is very little attacked. Mineral oils are practically without action unless acids are liberated.

That good concrete will successfully withstand concentrated salt and brine solutions is proven by the satisfactory service rendered by concrete tanks and other concrete structures in many salt plants.

At Wadsworth, Ohio, the Wadsworth Salt Co. has 14 concrete brine tanks, with a total capacity of 375,000 gals., that have been in service for eight years. At Hutchinson, Kan., the Carey Salt Co. has two concrete brine tanks built in 1917 that are subject to a range in temperature of over 220 degrees Fahrenheit. At Silver Springs, N. Y., the Worcester Salt Co. has five concrete salt grainers subject to a similar range of temperature that have given good service for six years. At Marine City, Mich., the Michigan Salt Works has 16 concrete tanks, with a total capacity of 1,150,000 gals., that are used for storing hot and cold brine.[6]

The Union Salt Co., of Cleveland, Ohio, state: "Concrete is especially suitable for salt plants—our six new buildings, erected in 1917, were all built in concrete, with concrete roofs." In addition to concrete salt making pans, which are 100 ft. long, 12 ft. wide, and 2 ft. deep, this company has several large concrete bins for the storage of wet and dry salt.

An interesting example of the extensive use of concrete at salt plants is at Pomeroy, Ohio, where the Rust Engineering Co., of Pittsburgh, built a large plant for the Pomeroy Chemical Co. in 1919.

The brine is a 10 per cent solution with a specific gravity of 7° Bé. It is heated to 68° C., and then is concentrated to a 20 per cent solution.

The brine then enters the concrete "mud-settlers" at a temperature of 84° C., where dirt and foreign materials are allowed to settle to the bottom, the brine being drawn off into concrete "draw settlers," and then into concrete "grainers," where copper steam pipes placed in the tank further concentrate the solution to about 35° Bé., until the salt precipitates and can be drawn off by means of a mechanical scraper, ready to be packed in barrels or bags for shipment to consumers. After the salt crystals are precipitated and carried away, the remaining liquid is turned into the concrete "Bittern grainer," where it is further concentrated, and pumped to stills where bromides and calcium chloride are separated, the residue being thrown away.

When the plant is in continuous operation, the temperature in the mud settlers is practically constant, varying only 4 or 5° C., but the temperature in the draw settlers varies widely, because the level of the brine changes with the filling of the grainers, but the draw settlers do not remain empty for any length of time. As the grainers are completely emptied when the salt crystals are removed, and are not immediately refilled, their temperature also varies, ranging from atmospheric temperature, which is sometimes zero, to 82° C. (176° F.).

The settler tanks are 158 ft. long, 11 ft. wide, and 3 ft. deep; the grainers are 158 ft. long, 11 ft. wide, and 1 ft. 8 in. deep. Owing to their length, these tanks were not built monolithic, but were constructed in sections about 13 ft. long, with bell joints, which allow a smooth inner surface.

When it is remembered that in the bittern grainer the concrete is in contact with concentrated brine of 40° Bé. gravity, it is evident that good concrete will withstand even concentrated brine solutions, because the plant has been in operation about four years and there are no appreciable signs of deterioration. The wide range in temperature, about 110° C., should also be noted.

Protective Coatings.

Four methods of treatment are recommended by the U. S. Bureau of Standards [7] for the protection of concrete floors, vats, tanks, reservoirs and other concrete surfaces against mineral acids and acid salts. The methods selected depend upon the character of surface to be covered, the concentration and temperature of the acid, and whether the coating is required to resist abrasion, and cost. The materials are bituminous compositions of various kinds.

Bituminous Paints.—Bituminous paints are used chiefly on account of their cheapness and ease of application and when properly applied have given fair protection against mineral acids and acid fumes of low concentrations, when not subjected to abrasion. They have been satisfactorily used on the walls of rooms and fume ducts and on tanks or other vessels with smooth walls such as are obtained with a plaster or grout coat. Two kinds are marketed: those made with an asphalt and those with a coal tar pitch base, thinned to the desired brushing consistency with suitable volatile solvents. For very dilute mineral acids paints made from either base are suitable, but asphalt paints appear to be somewhat more resistant than the coal tar paints against acids stronger than 10 per cent. Asbestos fiber is sometimes added in order to increase the thickness of coating obtained.

Bituminous paints will not resist abrasion and their effectiveness depends upon the thickness and imperviousness of the dried coating. Portland cement is very susceptible to acid of any strength, and consequently any pin holes due to faulty application or any abrasion in the surface will be sufficient to destroy the protection afforded by the coating. Once the acid penetrates the paint coating it will readily soak into and disintegrate the concrete beneath and cause the paint coating to form blisters which will ultimately flake off.

The most satisfactory method of applying bituminous paints is to use a thin priming coat to fill up the surface pores and thus obtain a good bond with the concrete surface, and when this is thoroughly dry, to apply carefully at least two coats of a thicker material of the same character or containing asbestos fiber, allowing sufficient time for the first coat to dry before the application of the second. The primer can be made by thinning the thicker material with a suitable volatile solvent. A petroleum distillate such as mineral spirits or turpentine substitute is generally used for asphaltic paints, and coal tar distillates as solvent naphtha for the coal tar paints. It is important that the concrete surface be thoroughly dry and fairly dust free. Special care should also be taken to touch up and recoat all dull, brown, porous, and uncoated spots. At least one week should elapse after the application of the last coat of paint before exposure to the acid.

Specifications.—A specification upon which satisfactory material has been obtained is as follows:

Acid-Proof Black:—This material shall be composed of a high grade of bitumen thinned with suitable volatile solvents to furnish a smooth, black product which shall dry in 24 hours and be unaffected by mineral acids of specified concentration.

It must contain at least 40 per cent of nonvolatile matter, must not liver or thicken in the container or show any precipitate which is not readily dispersed, on stirring, and must conform to the following requirements:

(a) When flowed on a piece of clean sheet iron approximately 10 cm. x 15 cm. x 0.4 mm. (4″ x 6″ x 0.016″) and allowed to dry for one week at room temperature, the film must withstand bending double quickly over a rod 5 mm. (1/5″) in diameter without cracking or flaking.

(b) A test piece prepared with two coats of the paint applied 24 hours apart and dried for one week at room temperature shall be laid flat and in different places several drops each of sulphuric acid sp. gr. 1.25, nitric acid, sp. gr. 1.12, and hydrochloric acid sp. gr. 1.09, shall be allowed to remain on the surface of the film for 6 hours at room temperature, about 21° C. (70° F.). The drops of acid shall be covered with watch glasses so as to prevent evaporation. After six hours the acid shall be washed off with tap water and the film shall then be allowed to dry for twelve hours and examined. The spots exposed to the acid shall show no disintegration or browning and the luster shall not be impaired.

Bituminous Enamels.—The bituminous enamels are used where protection for fairly long periods against relatively strong acids is desired, and when the cost of the structure justifies the extra expense of application. They can be employed both on smooth and rough walls and surfaces, and on account of the thickness of the coat used an impervious coating is more easily obtained. They will not resist abrasion at elevated temperatures.

The bituminous enamels consist of two materials, the priming solution and the enamel proper. The priming solution consists of a bituminous material, either asphalt or coal tar pitch, with a melting point sufficiently high to resist flow at the maximum temperature of service, and of low susceptibility to temperature changes, dissolved in sufficient volatile solvent to give a paint of thin brushing consistency. The enamel proper consists of a bituminous material similar to that used in the primer, with or without a finely powdered siliceous mineral filler. Although enamels are made without mineral filler, some mineral filler is regarded as desirable, as it increases the resistance of the enamel to flowing and sagging at elevated temperatures and to abrasion. The enamel is applied hot over the properly dried priming coat.

Specifications.—The following specifications should obtain material suitable for structures exposed to temperatures between 15.5° C. (60° F.) and 60° C. (140° F.).

Bituminous Enamel and Primer:—This material shall consist of a bituminous primer and a bituminous enamel which when applied to concrete surfaces will give a coating that will possess good adhesive qualities, will not flow or sag from vertical surfaces at the highest prevailing temperature, will not become brittle at 0° C. (32° F.) and will resist mineral acids of specified concentration for long periods.

Bituminous Enamel:—The enamel shall consist of a homogeneous mixture of a bituminous material and finely powdered siliceous mineral filler. The total amount of mineral filler, as determined from the ash, shall not exceed 40 per cent nor be less than 15 per cent by weight. Within the above limits the satisfactory working qualities of the enamel shall control the quantity of mineral filler used. The mineral filler must pass a No. 100 sieve and when boiled for 15 minutes in the acids of the strengths hereinafter specified shall show not more than 5 per cent of soluble material.

Bituminous Primer:—The primer shall consist of not less than 40 per cent of a bituminous material similar to that used in the enamel, shall contain no added mineral matter, and shall be thinned with a solvent to a satisfactory brushing consistency. It shall dry to a tacky state in 30 minutes, and shall not flash below 30° C. (86° F.) by the Tagliabue Closed Tester. The solvent used shall have a minimum toxic effect upon workmen applying the primer within an enclosed space.

Covering Power:—The materials shall have the following covering power: Bituminous Primer.—1 gallon shall cover not less than 9290 sq. cm. (100 sq. ft.) of surface. Bituminous Enamel.—1 pound shall cover not less than 186 sq. cm. (2 sq. ft.) of surface 1.6 mm. to 3.2 mm. (1/16″ to 1/8″) thick.

Application.—Extreme care should be taken in the application of these materials so as to obtain a continuous coat free from blisters and pinholes, and bonding well to the surface. The concrete surface should be as dry as possible, and free from oil and grease and all loose particles and dust. The primer then should be applied and should be worked thoroughly into all hollows and pores. As the bond between the concrete surface and the enamel coat depends to a great extent upon the proper application of the primer, before the application of the enamel, the primed surface should be thoroughly inspected and all brown, dull and uncoated spots should be touched up. When the primer has dried to a slightly tacky state, it is ready for the enamel.

The enamel should be melted and carefully heated until it is sufficiently fluid for brushing, avoiding decomposition and carbonization. The temperature of the material in the kettle should not exceed 218° C. (425° F.). When fluid it should be mopped on quickly, as it sets and hardens very rapidly. For structures below ground or those in which the temperature never exceeds 38° C. (100° F.), material melting at a lower temperature and made from a softer bituminous material may be used on account of its greater ease of application. It should not flow when exposed in a vertical position for five hours at 49° C. (120° F.) but should conform to the other requirements of the foregoing specifications.

Acid-Proof Asphalt Mastics.—Acid-proof asphalt mastics have been used extensively for floors and have given very satisfactory service in a wide variety of chemical and dye manufacturing plants, metal pickling, plating, acid tanks, and storage battery rooms, the pulp rooms of paper mills, in copper, gold, lead and other similar refineries, and in laboratories. Although used to some extent in the past in tanks, vats, and reservoirs for acids and acid liquors, this use for acid-proof asphalt mastic has developed greatly recently owing to the very satisfactory behavior of the material when exposed to acid conditions. In several copper refineries mastic has even been used for making pipes for carrying the acid liquors.

Acid-proof asphalt mastics are somewhat similar to the mixtures used in the construction of bituminous concrete, except that they contain a little more asphaltic cement, so that when hot and ready to lay they can be poured and are sufficiently plastic to be trowelled into place by wooden floats or light tamping irons. When mixed and ready for laying, they usually consist of about 10 to 15 per cent by weight of asphaltic cement, approximately 20 per cent by weight of finely powdered siliceous mineral filler, passing a No. 200 sieve, and the remainder properly graded sand or other acid resisting aggregate retained on a No. 200 sieve and containing no particles larger than those passing a No. 3 sieve. The asphaltic cement usually has a melting point of 60 to 99° C. (140 to 210° F.), depending upon the conditions of service of the finished mastic, and may be composed either of fluxed natural asphalts or properly prepared oil asphalts. The proper grading of the aggregate so as to get a mixture of maximum density is important, as upon it the stability and efficiency of the finished mastic largely depends.

The asphalt cement and finely powdered mineral matter can be mixed together on the job or they can be mixed by the manufacturer at his plant and shipped to the job in blocks or cakes called "mastic blocks" or "mastic cakes."

The use of mastic block is most common and is to be preferred. On very large jobs, however, it may be more economical to incorporate the fine mineral filler directly at the site of the work. In that case, although not absolutely necessary, instead of an iron kettle with hand stirring, it is better to use a rotary mastic machine, preferably of a type in which the products of combustion do not enter the mixing drum. With a machine of this type there is less danger of burning and overheating the mastic.

Mastic blocks consist of a mixture of asphalt cement of a definite melting point and consistency combined with the finely powdered mineral matter and sometimes part of the coarser aggregate. As much asphalt as possible is incorporated in the block without interfering with the shipping qualities of the latter. The blocks should not stick together nor lose their shape during shipment. Mastic block contains from 12 to 18 per cent of asphalt by weight, from 40 to 60 per cent by weight siliceous dust passing a No. 200 sieve and the remainder sand coarser than a No. 200 sieve, but passing a No. 3 sieve. It comes to the market in square, octagonal, circular, etc., shaped blocks or cakes weighing from 50 to 90 lbs. each.

In the laying of mastic, asphaltic materials called fluxes are used for tempering or increasing the asphalt content of the mixture. The fluxes are usually designated as "hard and soft fluxes." The "hard fluxes" are used for raising the melting point of the asphalt cement in the mastic, and the so-called soft fluxes for increasing the asphalt content without necessarily changing the melting point of the asphalt cement present. The "hard flux" generally is straight refined Trinidad asphalt, highly blown petroleum asphalt, fluxed grahamite, or wurtzelite pitch with a melting point (Ring and Ball Method) of approximately 93° C. (200° F.). The "soft flux" usually is fluxed Trinidad or low melting petroleum asphalts similar to the asphalt used in the mastic block. Occasionally, "fluxes" melting at temperatures below 60° C. (140° F.), between 71 to 82° C. (160 to 180° F.), and even as high as 138° C. (280° F.) are used for special purposes.

For use the blocks are broken up and placed in a mastic kettle or the drum of a mastic machine. Sufficient "hard or soft" is added to meet the particular conditions of the job, and the mixture is heated and stirred or mixed until the block is entirely disintegrated and the mass is homogeneous. The mineral aggregate is then added and the mass heated at approximately 218° C. (425° F.) with stirring until the mixture is homogeneous and sufficiently fluid for pouring.

Mastic is most effective when applied at least one inch thick; for flooring, when more than one inch is required, the mastic is laid in two courses of approximately equal thickness with staggered joints. In special instances wire mesh or expanded metal is used for reinforcing, particularly in tank work where there are vertical surfaces. For the latter the mastic is usually cast in a special form.

Specification.—A proposed specification for acid-proof asphalt mastic is as follows:

Acid-proof asphalt mastic shall be composed of asphalt cement, clean, sharp-grained sand and fine absorbent siliceous matter.

These materials shall be mixed in the proper proportions and shall be applied hot to the concrete surface which has been properly graded to drains and which shall be free from sharp projections, dirt and other foreign matter. Mastic blocks shall be used except where proper equipment is at hand for thoroughly incorporating the fine mineral filler into the asphalt.

The mastic block shall consist of asphalt, fine siliceous mineral filler, and other siliceous aggregate. The mineral filler and aggregate shall all pass a No. 20 sieve and sufficient fine material pass a No. 200 sieve shall be present in the block to give in the finished flooring from 20 to 25 per cent of mineral matter passing a No. 200 sieve. The asphalt shall have the following characteristics and shall constitute between 12 and 18 per cent by weight of the block:

Melting Point (Ring and Ball Method)..........	54.5-71° C. (130-160° F.)
Penetration at 25° C. (77° F.), 100 g., 5 sec.....	15-40
Ductility at 25° C. (77° F.)......................	min. 15 cm.
Volatile matter at 163° C. (325° F.) for 5 hrs...	1.5%

The blocks shall be prepared in suitable kettles with stirring so that all particles of the aggregate and filler are coated and a homogeneous mass is obtained, and shall be delivered on the job in blocks plainly marked with the brand of the manufacturers, and weighing between 50 and 90 lbs. each.

The "soft flux" shall preferably be similar to the asphalt cement used in the mastic block and shall have the following characteristics:

Melting Point (Ring and Ball Method)..........	54.5-71° C. (130-160° F.)
Penetration at 25° C. (77° F.), 100 g., 5 sec.....	15-40
Ductility at 25° C. (77° F.)......................	min. 15 cm.
Volatile matter at 163° C. (325° F.) for 5 hrs...	1.5%

The "hard flux" shall be either a refined or fluxed Trinidad asphalt or petroleum asphalt of the following characteristics:

Melting Point (Ring and Ball Method)..........	82-99° C. (180-210° F.)
Penetration at 25° C. (77° F.), 100 g., 5 sec.....	max., .10
Penetration at 46° C. (115° F.), 50 g., 5 sec.....	max., .20
Volatile matter at 163° C. (325° F.) for 5 hrs...	1.5%

The mineral aggregate shall be sand and small gravel. It shall be clean, hard-grained and free from clay, silt, limestone, organic and other foreign matter, and shall be properly graded from coarse to fine so as to produce a mixture of the greatest density and stability without interfering with the proper mixing and working of the materials.

When tested on the laboratory sieves it should have approximately the following characteristics:

Passing a No. 3 sieve	100%
Total passing a No. 8 sieve	40-60
Total passing a No. 30 sieve	10-40
Total passing a No. 100 sieve	0-10

If the local material available is not within the above requirements, it may be used provided that the finished mastic will have approximately the same density as mastic made with aggregate conforming to these specifications.

Use for Construction.—Mastic blocks shall be cracked and broken up into small pieces, weighed and placed in the mastic kettle or drum of the mastic machine. The proper quantity of "flux" of suitable grade to give the finished mastic the proper characteristics for the conditions of service to be met shall then be added. The block and "flux" shall be heated together and stirred with iron rods or by revolving the drum of the machine until the block is entirely disintegrated and the whole mass is fluid and homogeneous.

The mineral aggregate which should be dry and, if possible, heated beforehand, shall then be added and thoroughly stirred in. The heating and stirring shall be continued until all particles are thoroughly coated and the mass is sufficiently fluid to be poured and properly worked into place. The temperature of heating and mixing shall be as low as possible and at no time shall exceed 232° C. (450° F.). A maximum temperature of 218° C. (425° F.) is better, as there is less chance of burning and decomposing the asphalt. This should deliver a batch having a temperature of between 190.5 and 205° C. (375 and 400° F.).

When used for floors and horizontal surfaces, the hot mixtures shall then be carried from the kettle in reinforced oak buckets, iron wheelbarrows, or other suitable containers, and poured on the clean dry concrete surface. It shall then be smoothed out and worked under wooden floats until it is free from voids and has a uniform thickness of approximately 2.5 cm. (1 inch). It shall then be sprinkled with fine dry, sharp sand, and the surface rubbed smooth. In making joints hot mastic shall be spread at least 10.2 cm. (4 inches) over the edge of the cold mastic already in place, so that the cold edge will become soft and, after the excess material is removed, can be worked into a perfect bond with the new strip being laid.

When applied in the construction of tank walls and vertical surfaces, a wood or metal form with a slightly curved flare at the bottom to join with the mastic bottom shall be used. The side of the form to come in contact with the mastic shall be coated with a solution of soap, talc, or other siliceous dust and water to prevent sticking of this mastic. This form shall then be set far enough from the concrete wall or surface to be covered so as to give a mastic coating of the required thickness.

Expanded metal lath shall be used as a reinforcing for the mastic and shall be fastened by any suitable means to the concrete wall, etc. The concrete shall be primed with an asphalt paint and when the paint has dried to a tacky condition the hot mastic shall be poured into the form and worked and tamped so as to flow completely through the meshes of the lath and to form a dense mixture as free from voids as possible. When the mastic has cooled and set the form shall be removed and the surface of the mastic rubbed smooth with sharp grain sand.

Acid-proof Asphalt Flooring Composition.—Acid-proof asphalt flooring compositions for cold applications are sometimes improperly referred to by the term "mastic" or "mastic flooring" because they are used like true mastic for floors. The term "mastic," however, is very definite and is properly applied to those bituminous mixtures containing mineral filler and coarse sand or fine gravel which, when sufficiently heated, melt to a thick fluid mass that can be poured into place and can be spread and compacted by hand with wooden trowels, floats, or light rollers.

Acid-proof asphalt flooring compositions for cold application are of trowelling consistency and consist essentially of a relatively hard asphalt, asbestos, fiber, and finely powdered siliceous mineral filler, thinned with a volatile solvent. When the solvent evaporates, a very thin coherent coat of the intimately mixed asphalt and mineral matter is left behind.

Acid-proof asphalt flooring compositions are used chiefly where a thin surfacing for concrete floors is desired, as in laboratories which do not have to withstand any traffic heavier than walking. The black composition is most resistant to acid but where appearance is of importance, red, brown, and olive green are sometimes used. In that case only the top two or three coats of composition contain pigment.

In general four different compositions are used in applying these coatings, viz., primer, body coat, neat or finishing coat, and floor dressing.

The primer consists of about three parts of asphalt dissolved in seven parts of a volatile solvent. It is of fairly thin consistency and dries to a tacky state in from ½ to 3 hours in which condition it is suitable for the application of the succeeding coats. The asphalt used in the primer is similar to that used in the body coat and finishing coat and has a melting point (Ring and Ball Method) of 88 to 116° C. (190 to 240° F.) and a penetration at 25° C. (77° F.), 100 g. 5 sec., of about 10.

The body coat is always black in color, is of heavy trowelling consistency, and dries hard in from 12 to 48 hours. It consists of asphalt, asbestos fiber, small amounts of fine siliceous mineral matter, and a suitable volatile solvent.

For colors other than black a composition called the first colored top coat is used directly on top of the body coat and before the application of the neat or finishing coat. It dries hard in about the same time as the body coat and consists of asphalt, asbestos, fiber, pigment, and volatile solvent.

The neat or finishing coat may be black, red, olive green, or brown. It usually contains no asbestos. The black composition consists of asphalt, fine siliceous material, and solvent. The colored compositions contain pigments instead of part or all of the fine siliceous material.

The floor dressing is a very thin liquid of a varnish-like character and is applied like a varnish or floor dressing over the completed floor.

From the analysis of compositions of the above types received at the Bureau of Standards, the following general formulas have been obtained:

Constituents	Primer Per Cent	Body Coat Per Cent	First Top Coat (Red) Per Cent	Neat or Finishing Material (Red) Per Cent
Mineral spirits or other volatile solvent	65–70	33–42	30–36	25–32
Asphalt	30–35	12–16	8–20	10–11
Asbestos and fine siliceous material	.....	42–55	20–22	0–5
Pigment	.....	.....	30–34	57–60

FLOOR DRESSING

Mineral spirits	70–85 per cent
Non-volatile (oil or resin)	15–30 per cent

For the application of a floor of this type over concrete the following procedure is generally used: The clean, dry, dust-free concrete is given one coat of the primer with a brush and when this has dried to the tacky state, which requires usually from one-half to three hours, a thin layer, about 0.8 mm. ($\frac{1}{32}$ inch) thick, of the body coat composition is trowelled on and smoothed out. When this has dried for 24 to 48 hours, it is rolled with a light wood or iron roller, and successive 0.8 mm. ($\frac{1}{32}$ inch) coats of the body composition are applied until the required thickness is obtained. The floor is then finished with one or two 0.8 mm. ($\frac{1}{32}$ inch) coats of the neat or finishing material. In the case of colored floors, a coat of the first colored top composition is substituted for one coat of the body composition. When the completed floor has dried for about 48 hours it is given a final rolling and then a thin coat of the floor dressing which dries to a gloss and prevents dusting to some extent, or it can be given a coating of a good floor wax applied in the ordinary way.

The chemical research division of the U. S. S. Lead Refinery Inc., East Chicago, Ill., has produced a proprietary solution of interest to industries where acids or oils enter into the processes, because the tests show that ordinary concrete is rendered practically inactive to acid solutions and oils.

The concrete surface at the time of each treatment must be free from dirt, oil or grease, and must be dry and set at the time of the first application. One part of proofing solution is diluted with two parts of water and applied with a brush. After allowing to stand for twenty-four hours the second coat is put on, consisting of equal parts of proofing solution and water. This is allowed to stand for twenty-four hours and a third coat is applied, consisting of two parts of proofing solution to one part of water. When the concrete is very porous a fourth application of straight proofing solution is recommended. At the completion of the process the surface is dry and flushed with water. When the solution is thus brought into contact with the concrete it precipitates acid-resisting compounds into the pores of the mass, causing the new surface to become an entirely different chemical composition from the original concrete, this effect penetrating to a depth of about 1/8 inch. This new surface chemically formed is hard and flint like in structure and is not attacked by any ordinary acid solutions or oils. It is also very hard and resistant to wear.

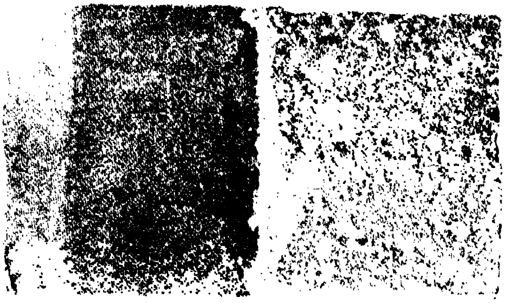

FIG. 21.—Comparison of Effect of Acid on Protected and Unprotected Concrete.

It is now in use on floors subjected to acid slops at the Willard Storage Battery Company and is being used by a number of chemical firms for the construction of acid tanks, and is claimed to be superior to acid-proof brick.

The illustration shows a comparison between a treated and untreated slab of concrete which has been immersed in a 20 per cent acetic acid solution for upwards of 20 days.

F. W. Frerichs[8] describes in detail the installation of large concrete tanks for the storing of ammoniacal liquors. Description is also given of permeability tests. Storage tanks of ammoniacal liquors are usually constructed of steel. On account of war conditions steel plates were not available and it was decided to construct the tanks of concrete.

Preliminary experiments indicated that crude and ammoniacal liquors did not affect good concrete. Four small experimental tanks were constructed and subjected to tests in order to ascertain the permeability of concrete walls to water and aqua-ammonia. One tank was made of cement concrete consisting of one part cement, two parts sand and four parts gravel. This was numbered "A." Tank "B" was made from the same mix with two per cent hydrated lime added before mixing. Tanks "C" and "D" contained two per cent each of two stearate waterproof materials on the market. The tanks were located in the open air exposed to the sun and the outside surface appeared dry. After ten days' drying, tests were conducted to ascertain the permeability of the tanks to water and to ammoniacal liquor.

Permeability to water.—Tanks were filled with water 18 inches high to within 6 inches from top and the iron covers luted on tightly with cement. Counting the decrease for the first day for saturation of the concrete, then the average evaporation per day per square foot outside area (25 square feet) was for "A" 2.8 cubic inches; "B" 1.0 cubic inches; "C" 0.7 cubic inches; "D" 2.8 cubic inches.

Permeability to 18 inch aqua-ammonia.—Tanks were filled with aqua-ammonia to within 6 inches from top and the iron covers luted on tightly with cement. Counting the decrease for the first two days for saturation of the concrete, then the average evaporation per day per square foot outside area exposed to the atmosphere (25 square feet) was for "A" 3.5 cubic inches; "B" 1.0 cubic inches; "C" 1.25 cubic inches; "D" 1.02 cubic inches.

The tanks were then dried and painted on the inside with three coats of raw gas tar. The tar used for the first coat was thinned down with about 10 per cent turpentine, which caused the tar to penetrate about 1/8 inch into the concrete. After one weeks' drying, the tanks were tested again with ammoniacal liquor and during several months there was no appreciable loss.

Other small experimental tanks were then built with and without waterproof compounds mixed with the concrete. The plain concrete tanks proved as water tight as those in which the compounds were used. It was concluded from these experiments that waterproof tanks could be built and three large tanks (35 feet inside diameter by 26 feet deep) were then built in a concrete pit. Excavation was made in the slope of a river bank, partly in earth and partly in solid rock. The bottom, sides, and walls rested on solid rock and all necessary engineering precautions were taken. Methods of construction are outlined and emphasis is given to the importance of continuous concreting from the time walls are started. The concrete in the tank walls is composed of one part red ring Portland cement, two parts sand, and three parts washed and screened Meramec gravel. The tanks were dried out, the bottom, sides and roof of the interior were coated with three coats of tar applied with a brush as an additional precaution against leakage and liquid gas. The tanks were then tested. There was some leakage through slight lifting cracks in the walls of the first tank built. This was due to the slow movement of the forms. Such cracks were avoided by more rapid movement of forms on the balance of the work and the leaks gradually healed and disappeared. Tank capacity is about 185,000 gallons and cost approximately $10,000 exclusive of the tank pit.

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APPENDIX

In the following pages the authors have attempted to assemble a few tables which will be of value in connection with the use of this book. In compiling appendixes of this character it is difficult to know where to stop and it would be easy to expand such a collection into a small engineering handbook. We have endeavored to include only such tables as are likely to be very frequently referred to, thus saving the reader the trouble of turning to another volume for necessary data. We have also included some tables of the physical properties of certain metals and alloys which are particularly important in connection with chemical engineering work. In most instances, these tables have been culled from current technical literature and are not found in the standard engineering handbooks. We have not included tables of physical properties of the ordinary engineering metals such as iron, steel and copper, for the reason that these are readily available in such handbooks and are given there in much more extended form than would be possible in these pages.

Every effort has been made to insure accuracy in the copying of the tables given in this Appendix, but the authors have not attempted to check the original data in any way.

Grateful acknowledgement is made of the various sources from which the tables have been obtained.

DEFINITIONS

MOLAR

Molar solutions are solutions containing one formula weight of substance, expressed in grams, per liter of solution. Example: The formula weight or molecular weight of sulfuric acid, H_2SO_4, is in round numbers 98. It is obtained by adding together the atomic weights of the constituent atoms. A molar solution of sulfuric acid therefore contains 98 grams of sulfuric acid per liter.

NORMAL

The idea of a normal solution of a base or acid is based on the number of ionizable hydroxyl groups or hydrogens it contains. A normal solution of an acid contains an amount of acid per liter of solution equal to the formula weight expressed in grams divided by the number of ionizable hydrogens in the molecule. A normal solution of a base contains an amount of base per liter equal to the formula weight expressed in grams divided by the number of ionizable hydroxyl groups in the molecule. Example: Sulfuric acid contains two ionizable hydrogens; consequently a normal solution contains ½ formula weight, or 49 grams per liter.

CONCENTRATION

The concentration of solute in a solution is usually expressed in terms of gram formula weights per liter or grams per liter. It is a weight-volume ratio and does not bear a simple relation to percentage or molar percentage which are weight-weight ratios.

DENSITY AND SPECIFIC GRAVITY

The density of a liquid or a gas is the weight in grams of one cubic centimeter; it varies with pressure and temperature. The specific gravity of a liquid is the ratio of the weight of a given volume of the liquid to the weight of the same volume of water at a definite temperature. The reference temperature for water is variously chosen as that of the liquid in question, 4° C (maximum density of water) or 0° C. The specific gravity of a gas is usually taken as the ratio of the weight of a given volume of gas at one atmosphere pressure and 0° C to the weight of the same volume of air or of hydrogen at the same pressure and temperature.

ELECTROLYTIC ACTION

When two different metals, or a metal and certain inert electrical conductors are placed in a conducting solution they develop different electric potentials. If they are in electrical contact, a cell is formed and a current flows caused by a chemical reaction which results in the solution or disintegration of one or both of the electrodes. Such conditions are met with frequently in industrial work and are often the cause of severe corrosion.

COMBINING (ATOMIC) WEIGHTS

O = 16

Aluminum	Al	27.1
Antimony	Sb	120.2
Argon	A	39.88
Arsenic	As	74.96
Barium	Ba	137.37
Bismuth	Bi	208.0
Boron	B	11.0
Bromine	Br	79.92
Cadmium	Cd	112.40
Cæsium	Cs	132.81
Calcium	Ca	40.07
Carbon	C	12.005
Cerium	Ce	140.25
Chlorine	Cl	35.46
Chromium	Cr	52.0
Cobalt	Co	58.97
Columbium	Cb	93.1
Copper	Cu	63.57
Dysprosium	Dy	162.5
Erbium	Er	167.7
Europium	Eu	152.0
Fluorine	F	19.0
Gadolinium	Gd	157.3
Gallium	Ga	69.9
Germanium	Ge	72.5
Glucinum	Gl	9.1
Gold	Au	197.2
Helium	He	4.00
Holmium	Ho	163.5
Hydrogen	H	1.008
Indium	In	114.8
Iodine	I	126.92
Iridium	Ir	193.1
Iron	Fe	55.84
Krypton	Kr	82.92
Lanthanum	La	139.0
Lead	Pb	207.20
Lithium	Li	6.94
Lutecium	Lu	175.0
Magnesium	Mg	24.32
Manganese	Mn	54.93
Mercury	Hg	200.6
Molybdenum	Mo	96.0
Neodymium	Nd	144.3
Neon	Ne	20.2
Nickel	Ni	58.68
Niton	Nt	222.4
Nitrogen	N	14.01
Osmium	Os	190.9
Oxygen	O	16.00
Palladium	Pd	106.7
Phosphorus	P	31.04
Platinum	Pt	195.2
Potassium	K	39.10
Praseodymium	Pr	140.9
Radium	Ra	226.0
Rhodium	Rh	102.9
Rubidium	Rb	85.45
Ruthenium	Ru	101.7
Samarium	Sa	150.4
Scandium	Sc	44.1
Selenium	Se	79.2
Silicon	Si	28.3
Silver	Ag	107.88
Sodium	Na	23.00
Strontium	Sr	87.63
Sulphur	S	32.06
Tantalum	Ta	181.5
Tellurium	Te	127.5
Terbium	Tb	159.2
Thallium	Tl	204.0
Thorium	Th	232.4
Thulium	Tm	168.5
Tin	Sn	118.7
Titanium	Ti	48.1
Tungsten	W	184.0
Uranium	U	238.2
Vanadium	V	51.0
Xenon	Xe	130.2
Ytterbium (Neoytterbium)	Yb	173.5
Yttrium	Y	88.7
Zinc	Zn	65.37
Zirconium	Zr	90.6

DOMESTIC WEIGHTS AND MEASURES

Apothecaries' Weight

20 grains	1 scruple
3 scruples	1 dram
8 drams	1 ounce
12 ounces	1 pound

Avoirdupois Weight
(short ton)

$27\frac{11}{32}$ grains	1 dram
16 drams	1 ounce
16 ounces	1 pound
14 pounds	1 stone
25 pounds	1 quarter
4 quarters	1 hundredweight (cwt)
20 hundredweights	1 ton

Avoirdupois Weight
(long ton)

$27\frac{11}{32}$ grains	1 dram
16 drams	1 ounce
16 ounces	1 pound
112 pounds	1 hundredweight
20 hundredweights	1 ton

Circular Measure

60 seconds	1 minute
60 minutes	1 degree
30 degrees	1 sign
12 signs	1 circle or circumference

Cubic Measure

1728 cubic inches	1 cubic foot
27 cubic feet	1 cubic yard

Dry Measure

2 pints	1 quart
8 quarts	1 peck
4 pecks	1 bushel

Liquid Measure

4 gills	1 pint
2 pints	1 quart
4 quarts	1 gallon
31½ gallons	1 barrel
2 barrels	1 hogshead

Long Measure

12 inches	1 foot
3 feet	1 yard
5½ yards	1 rod or pole
40 rods	1 furlong
8 furlongs	1 statute mile
5280 feet	1 statute mile
1760 yards	1 statute mile
3 miles	1 league

Mariner's Measure

6 feet	1 fathom
120 fathoms	1 cable length
7½ cable lengths	1 mile
5280 feet	1 statute mile
6085 feet	1 nautical mile

Paper Measure

24 sheets	1 quire
20 quires	1 short ream
500 sheets	1 long ream
2 reams	1 bundle
5 bundles	1 bale

Square Measure

144 square inches	1 square foot
9 square feet	1 square yard
30¼ square yards	1 square rod or perch
40 square rods	1 rood
4 roods	1 acre
640 acres	1 square mile
36 square miles	1 township

Troy Weight

24 grains	1 pennyweight
20 pennyweights	1 ounce
12 ounces	1 pound

METRIC EQUIVALENTS

	Approximate		Exact
1 acre	0.40	hectare	0.4047
1 bushel	35.	liters	35.24
1 centimeter	0.39	inch	0.3937
1 cubic centimeter	0.061	cubic inch	0.0610
1 cubic foot	0.028	cubic meter	0.0283
1 cubic inch	16.	cubic centimeters	16.39
1 cubic meter	35.	cubic feet	35.31
1 cubic meter	1.3	cubic yards	1.308
1 cubic yard	0.76	cubic meter	0.7646
1 foot	30.	centimeters	30.48
1 gallon (U. S.)	3.8	liters	3.785
1 gallon (Imperial)	4.5	liters	4.546
1 grain	0.065	gram	0.0648
1 gram	15.	grains	15.43
1 hectare	2.5	acres	2.471
1 inch	25.	millimeters	25.40
1 kilogram (kilo)	2.2	pounds	2.205
1 kilometer	0.62	mile	0.6214
1 liter	0.91	quart (dry)	0.9081
1 liter	1.1	quarts (liquid) (U. S.)	1.057
1 liter	0.88	quart (liquid) (Imperial)	0.8799
1 meter	3.3	feet	3.281
1 mile	1.6	kilometers	1.609
1 millimeter	0.039	inch	0.0394
1 ounce (av'd)	28.	grams	28.35
1 ounce (Troy)	31.	grams	31.10
1 peck	8.8	liters	8.810
1 pint (liquid)	0.47	liter	0.4732
1 pound	0.45	kilogram	0.4536
1 quart (dry)	1.1	liters	1.101
1 quart (liquid)	0.95	liter	0.9463
1 square centimeter	0.15	square inch	0.1550
1 square foot	0.093	square meter	0.0929
1 square inch	6.5	square centimeters	6.452
1 square meter	1.2	square yards	1.196
1 square meter	11.	square feet	10.76
1 square yard	0.84	square meter	0.8361
1 ton (2,000 lbs.)	0.91	metric ton	0.9072
1 ton (2,240 lbs.)	1.	metric ton	1.016
1 ton (metric)	1.1	ton (2,000 lbs.)	1.102
1 ton (metric)	0.98	ton (2,240 lbs.)	0.9842
1 yard	0.91	meter	0.9144

Relations of British and American Units

1 U. S. gallon = 0.83268 Imperial gallon
1 U. S. bushel = 0.96945 Imperial bushel
1 Imperial gallon = 1.20094 U. S. gallon
1 Imperial bushel = 1.03151 U. S. bushel
Imperial gallon = approx. 277 c. in.
Imperial bushel = approx. 2219 c. in.
1 British gallon ale or beer = 1.2208 U. S. gallon
Barrel (British) or tierce = 42 gallons
Barrel (U. S. liquid, oil, etc.) = 31.5 gallons

EQUIVALENT TEMPERATURE READINGS FOR FAHRENHEIT AND CENTIGRADE SCALES

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
-459.4	-273.	**-21.**	-29.44	17.60	**- 8.**	**56.**	13.33
-436.	-270.	-20.20	**-29.**	**18.**	- 7.78	**57.**	13.89
-418.	-260.	**-20.**	-28.89	**19.**	- 7.22	57.20	**14.**
-400.	-240.	**-19.**	-28.33	19.40	**- 7.**	**58.**	14.44
-382.	-230.	-18.40	**-28.**	**20.**	- 6.67	**59.**	**15.**
-364.	-220.	**-18.**	-27.78	**21.**	- 6.11	**60.**	15.56
-346.	-210.	**-17.**	-27.22	21.20	**- 6.**	60.80	**16.**
-328.	-200.	-16.60	**-27.**	**22.**	- 5.56	**61.**	16.11
-310.	-190.	**-16.**	-26.67	**23.**	**- 5.**	**62.**	16.67
-292.	-180.	**-15.**	-26.11	**24.**	- 4.44	62.60	**17.**
-274.	-170.	-14.80	**-26.**	24.80	**- 4.**	**63.**	17.22
-256.	-160.	**-14.**	-25.56	**25.**	- 3.89	**64.**	17.78
-238.	-150.	**-13.**	**-25.**	**26.**	- 3.33	64.40	**18.**
-220.	-140.	**-12.**	-24.44	26.60	**- 3.**	**65.**	18.33
-202.	-130.	-11.20	**-24.**	**27.**	- 2.78	**66.**	18.89
-184.	-120.	**-11.**	-23.89	**28.**	- 2.22	66.20	**19.**
-166.	-110.	**-10.**	-23.33	28.40	**- 2.**	**67.**	19.44
-148.	-100.	- 9.40	**-23.**	**29.**	- 1.67	**68.**	**20.**
-139.	- 95.	**- 9.**	-22.78	**30.**	- 1.11	**69.**	20.56
-130.	- 90.	**- 8.**	-22.22	30.20	**- 1.**	69.80	**21.**
-121.	- 85.	- 7.60	**-22.**	**31.**	- 0.56	**70.**	21.11
-112.	- 80.	**- 7.**	-21.67	**32.**	**0.**	**71.**	21.67
-103.	- 75.	**- 6.**	-21.11	**33.**	+ 0.56	71.60	**22.**
- 94.	- 70.	- 5.80	**-21.**	33.80	**1.**	**72.**	22.22
- 85.	- 65.	**- 5.**	-20.56	**34.**	1.11	**73.**	22.78
- 76.	- 60.	**- 4.**	**-20.**	**35.**	1.67	73.40	**23.**
- 67.	- 55.	**- 3.**	-19.44	35.60	**2.**	**74.**	23.33
- 58.	- 50.	- 2.20	**-19.**	**36.**	2.22	**75.**	23.89
- 49.	- 45.	**- 2.**	-18.89	**37.**	2.78	75.20	**24.**
- 40.	**- 40.**	**- 1.**	-18.33	37.40	**3.**	**76.**	24.44
- 39.	- 39.44	-0.40	**-18.**	**38.**	3.33	**77.**	**25.**
- 38.20	**- 39.**	0.	-17.78	**39.**	3.89	**78.**	25.56
- 38.	- 38.89	**+ 1.**	-17.22	39.20	**4.**	78.80	**26.**
- 37.	- 38.33	1.40	**-17.**	**40.**	4.44	**79.**	26.11
- 36.40	**- 38.**	**2.**	-16.67	**41.**	**5.**	**80.**	26.67
- 36.	- 37.78	**3.**	-16.11	**42.**	5.56	80.60	**27.**
- 35.	- 37.22	3.20	**-16.**	42.80	**6.**	**81.**	27.22
- 34.60	**- 37.**	**4.**	-15.56	**43.**	6.11	**82.**	27.78
- 34.	- 36.67	**5.**	**-15.**	**44.**	6.67	82.40	**28.**
- 33.	- 36.11	**6.**	-14.44	44.60	**7.**	**83.**	28.33
- 32.80	**- 36.**	6.80	**-14.**	**45.**	7.22	**84.**	28.89
- 32.	- 35.56	**7.**	-13.89	**46.**	7.78	84.20	**29.**
- 31.	**- 35.**	**8.**	-13.33	46.40	**8.**	**85.**	29.44
- 30.	- 34.44	8.60	**-13.**	**47.**	8.33	**86.**	**30.**
- 29.20	**- 34.**	**9.**	-12.78	**48.**	8.89	**87.**	30.56
- 29.	- 33.89	**10.**	-12.22	48.20	**9.**	87.80	**31.**
- 28.	- 33.33	10.40	**-12.**	**49.**	9.44	**88.**	31.11
- 27.40	**- 33.**	**11.**	-11.67	**50.**	**10.**	**89.**	31.67
- 27.	- 32.78	**12.**	-11.11	**51.**	10.56	89.60	**32.**
- 26.	- 32.22	12.20	**-11.**	51.80	**11.**	**90.**	32.22
- 25.60	**- 32.**	**13.**	-10.56	**52.**	11.11	**91.**	32.78
- 25.	- 31.67	**14.**	**-10.**	**53.**	11.67	91.40	**33.**
- 24.	- 31.11	**15.**	- 9.44	53.60	**12.**	**92.**	33.33
- 23.80	**- 31.**	15.80	**- 9.**	**54.**	12.22	**93.**	33.89
- 23.	- 30.56	**16.**	- 8.89	**55.**	12.78	93.20	**34.**
- 22.	**- 30.**	**17.**	- 8.33	55.40	**13.**	**94.**	34.44

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales (Continued)

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
95.	35.	134.	56.67	172.40	78.	211.	99.44
96.	35.56	134.60	57.	173.	78.33	212.	100.
96.80	36.	135.	57.22	174.	78.89	213.	100.56
97.	36.11	136.	57.78	174.20	79.	213.80	101.
98.	36.67	136.40	58.	175.	79.44	214.	101.11
98.60	37.	137.	58.33	176.	80.	215.	101.67
99.	37.22	138.	58.89	177.	80.56	215.60	102.
100.	37.78	138.20	59.	177.80	81.	216.	102.22
100.40	38.	139.	59.44	178.	81.11	217.	102.78
101.	38.33	140.	60.	179.	81.67	217.40	103.
102.	38.89	141.	60.56	179.60	82.	218.	103.33
102.20	39.	141.80	61.	180.	82.22	219.	103.89
103.	39.44	142.	61.11	181.	82.78	219.20	104.
104.	40.	143.	61.67	181.40	83.	220.	104.44
105.	40.56	143.60	62.	182.	83.33	221.	105.
105.80	41.	144.	62.22	183.	83.89	222.	105.56
106.	41.11	145.	62.78	183.20	84.	222.80	106.
107.	41.67	145.40	63.	184.	84.44	223.	106.11
107.60	42.	146.	63.33	185.	85.	224.	106.67
108.	42.22	147.	63.89	186.	85.56	224.60	107.
109.	42.78	147.20	64.	186.80	86.	225.	107.22
109.40	43.	148.	64.44	187.	86.11	226.	107.78
110.	43.33	149.	65.	188.	86.67	226.40	108.
111.	43.89	150.	65.56	188.60	87.	227.	108.33
111.20	44.	150.80	66.	189.	87.22	228.	108.89
112.	44.44	151.	66.11	190.	87.78	228.20	109.
113.	45.	152.	66.67	190.40	88.	229.	109.44
114.	45.56	152.60	67.	191.	88.33	230.	110.
114.80	46.	153.	67.22	192.	88.89	231.	110.56
115.	46.11	154.	67.78	192.20	89.	231.80	111.
116.	46.67	154.40	68.	193.	89.44	232.	111.11
116.60	47.	155.	68.33	194.	90.	233.	111.67
117.	47.22	156.	68.89	195.	90.56	233.60	112.
118.	47.78	156.20	69.	195.80	91.	234.	112.22
118.40	48.	157.	69.44	196.	91.11	235.	112.78
119.	48.33	158.	70.	197.	91.67	235.40	113.
120.	48.89	159.	70.56	197.60	92.	236.	113.33
120.20	49.	159.80	71.	198.	92.22	237.	113.89
121.	49.44	160.	71.11	199.	92.78	237.20	114.
122.	50.	161.	71.67	199.40	93.	238.	114.44
123.	50.56	161.60	72.	200.	93.33	239.	115.
123.80	51.	162.	72.22	201.	93.89	240.	115.56
124.	51.11	163.	72.78	201.20	94.	240.80	116.
125.	51.67	163.40	73.	202.	94.44	241.	116.11
125.60	52.	164.	73.33	203.	95.	242.	116.67
126.	52.22	165.	73.89	204.	95.56	242.60	117.
127.	52.78	165.20	74.	204.80	96.	243.	117.22
127.40	53.	166.	74.44	205.	96.11	244.	117.78
128.	53.33	167.	75.	206.	96.67	244.40	118.
129.	53.89	168.	75.56	206.60	97.	245.	118.33
129.20	54.	168.80	76.	207.	97.22	246.	118.89
130.	54.44	169.	76.11	208.	97.78	246.20	119.
131.	55.	170.	76.67	208.40	98.	247.	119.44
132.	55.56	170.60	77.	209.	98.33	248.	120.
132.80	56.	171.	77.22	210.	98.89	249.	120.56
133.	56.11	172.	77.78	210.20	99.	249.80	121.

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales (Continued)

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
250.	121.11	**289.**	142.78	327.20	**164.**	366.80	**186.**
251.	121.67	289.40	**143.**	**328.**	164.44	**367.**	186.11
251.60	**122.**	**290.**	143.33	**329.**	**165.**	**368.**	186.67
252.	122.22	**291.**	143.89	**330.**	165.56	368.60	**187.**
253.	122.78	291.20	**144.**	330.80	**166.**	**369.**	187.22
253.40	**123.**	**292.**	144.44	**331.**	166.11	**370.**	187.78
254.	123.33	**293.**	**145.**	**332.**	166.67	370.40	**188.**
255.	123.89	**294.**	145.56	332.60	**167.**	**371.**	188.33
255.20	**124.**	294.80	**146.**	**333.**	167.22	**372.**	188.89
256.	124.44	**295.**	146.11	**334.**	167.78	372.20	**189.**
257.	**125.**	**296.**	146.67	334.40	**168.**	**373.**	189.44
258.	125.56	296.60	**147.**	**335.**	168.33	**374.**	**190.**
258.80	**126.**	**297.**	147.22	**336.**	168.89	**375.**	190.56
259.	126.11	**298.**	147.78	336.20	**169.**	375.80	**191.**
260.	126.67	298.40	**148.**	**337.**	169.44	**376.**	191.11
260.60	**127.**	**299.**	148.33	**338.**	**170.**	**377.**	191.67
261.	127.22	**300.**	148.89	**339.**	170.56	377.60	**192.**
262.	127.78	300.20	**149.**	339.80	**171.**	**378.**	192.22
262.40	**128.**	**301.**	149.44	**340.**	171.11	**379.**	192.78
263.	128.33	**302.**	**150.**	**341.**	171.67	379.40	**193.**
264.	128.89	**303.**	150.56	341.60	**172.**	**380.**	193.33
264.20	**129.**	303.80	**151.**	342.	172.22	**381.**	193.89
265.	129.44	**304.**	151.11	**343.**	172.78	381.20	**194.**
266.	**130.**	**305.**	151.67	343.40	**173.**	**382.**	194.44
267.	130.56	305.60	**152.**	344.	173.33	**383.**	**195.**
267.80	**131.**	**306.**	152.22	**345.**	173.89	**384.**	195.56
268.	131.11	**307.**	152.78	345.20	**174.**	384.80	**196.**
269.	131.67	307.40	**153.**	**346.**	174.44	**385.**	196.11
269.60	**132.**	**308.**	153.33	**347.**	**175.**	**386.**	196.67
270.	132.22	**309.**	153.89	**348.**	175.56	386.60	**197.**
271.	132.78	309.20	**154.**	348.80	**176.**	**387.**	197.22
271.40	**133.**	**310.**	154.44	**349.**	176.11	**388.**	197.78
272.	133.33	**311.**	**155.**	**350.**	176.67	388.40	**198.**
273.	133.89	**312.**	155.56	350.60	**177.**	**389.**	198.33
273.20	**134.**	312.80	**156.**	**351.**	177.22	**390.**	198.89
274.	134.44	**313.**	156.11	**352.**	177.78	390.20	**199.**
275.	**135.**	**314.**	156.67	352.40	**178.**	**391.**	199.44
276.	135.56	314.60	**157.**	**353.**	178.33	**392.**	**200.**
276.80	**136.**	**315.**	157.22	**354.**	178.89	**393.**	200.56
277.	136.11	**316.**	157.78	354.20	**179.**	393.80	**201.**
278.	136.67	316.40	**158.**	**355.**	179.44	**394.**	201.11
278.60	**137.**	**317.**	158.33	**356.**	**130.**	**395.**	201.67
279.	137.22	**318.**	158.89	**357.**	180.56	395.60	**202.**
280.	137.78	318.20	**159.**	357.80	**181.**	**396.**	202.22
280.40	**138.**	**319.**	159.44	**358.**	181.11	**397.**	202.78
281.	138.33	**320.**	**160.**	359.	181.67	397.40	**203.**
282.	138.89	**321.**	160.56	359.60	**182.**	**398.**	203.33
282.20	**139.**	321.80	**161.**	**360.**	182.22	**399.**	203.89
283.	139.44	**322.**	161.11	**361.**	182.78	399.20	**204.**
284.	**140.**	**323.**	161.67	361.40	**183.**	**400.**	204.44
285.	140.56	323.60	**162.**	**362.**	183.33	**401.**	**205.**
285.80	**141.**	**324.**	162.22	**363.**	183.89	**402.**	205.56
286.	141.11	**325.**	162.78	363.20	**184.**	402.80	**206.**
287.	141.67	325.40	**163.**	**364.**	184.44	**403.**	206.11
287.60	**142.**	**326.**	163.33	**365.**	**185.**	**404.**	206.67
288.	142.22	**327.**	163.89	**366.**	185.56	404.60	**207.**

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales (Continued)

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
405.	207.22	444.	228.89	483.	250.56	521.60	272.
406.	207.78	444.20	229.	483.80	251.	522.	272.22
406.40	208.	445.	229.44	484.	251.11	523.	272.78
407.	208.33	446.	230.	485.	251.67	523.40	273.
408.	208.89	447.	230.56	485.60	252.	524.	273.33
408.20	209.	447.80	231.	486.	252.22	525.	273.89
409.	209.44	448.	231.11	487.	252.78	525.20	274.
410.	210.	449.	231.67	487.40	253.	526.	274.44
411.	210.56	449.60	232.	488.	253.33	527.	275.
411.80	211.	450.	232.22	489.	253.89	528.	275.56
412.	211.11	451.	232.78	489.20	254.	528.80	276.
413.	211.67	451.40	233.	490.	254.44	529.	276.11
413.60	212.	452.	233.33	491.	255.	530.	276.67
414.	212.22	453.	233.89	492.	255.56	530.60	277.
415.	212.78	453.20	234.	492.80	256.	531.	277.22
415.40	213.	454.	234.44	493.	256.11	532.	277.78
416.	213.33	455.	235.	494.	256.67	532.40	278.
417.	213.89	456.	235.56	494.60	257.	533.	278.33
417.20	214.	456.80	236.	495.	257.22	534.	278.89
418.	214.44	457.	236.11	496.	257.78	534.20	279.
419.	215.	458.	236.67	496.40	258.	535.	279.44
420.	215.56	458.60	237.	497.	258.33	536.	280.
420.80	216.	459.	237.22	498.	258.89	537.	280.56
421.	216.11	460.	237.78	498.20	259.	537.80	281.
422.	216.67	460.40	238.	499.	259.44	538.	281.11
422.60	217.	461.	238.33	500.	260.	539.	281.67
423.	217.22	462.	238.89	501.	260.56	539.60	282.
424.	217.78	462.20	239.	501.80	261.	540.	282.22
424.40	218.	463.	239.44	502.	261.11	541.	282.78
425.	218.33	464.	240.	503.	261.67	541.40	283.
426.	218.89	465.	240.56	503.60	262.	542.	283.33
426.20	219.	465.80	241.	504.	262.22	543.	283.89
427.	219.44	466.	241.11	505.	262.78	543.20	284.
428.	220.	467.	241.67	505.40	263.	544.	284.44
429.	220.56	467.60	242.	506.	263.33	545.	285.
429.80	221.	468.	242.22	507.	263.89	546.	285.56
430.	221.11	469.	242.78	507.20	264.	546.80	286.
431.	221.67	469.40	243.	508.	264.44	547.	286.11
431.60	222.	470.	243.33	509.	265.	548.	286.67
432.	222.22	471.	243.89	510.	265.56	548.60	287.
433.	222.78	471.20	244.	510.80	266.	549.	287.22
433.40	223.	472.	244.44	511.	266.11	550.	287.78
434.	223.33	473.	245.	512.	266.67	550.40	288.
435.	223.89	474.	245.56	512.60	267.	551.	288.33
435.20	224.	474.80	246.	513.	267.22	552.	288.89
436.	224.44	475.	246.11	514.	267.78	552.20	289.
437.	225.	476.	246.67	514.40	268.	553.	289.44
438.	225.56	476.60	247.	515.	268.33	554.	290.
438.80	226.	477.	247.22	516.	268.89	555.	290.56
439.	226.11	478.	247.78	516.20	269.	555.80	291.
440.	226.67	478.40	248.	517.	269.44	556.	291.11
440.60	227.	479.	248.33	518.	270.	557.	291.67
441.	227.22	480.	248.89	519.	270.56	557.60	292.
442.	227.78	480.20	249.	519.80	271.	558.	292.22
442.40	228.	481.	249.44	520.	271.11	559.	292.78
443.	228.33	482.	250.	521.	271.67	559.40	293.

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales (Continued)

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
560.	293.33	599.	315.	638.	336.67	676.40	358.
561.	293.89	600.	315.56	638.60	337.	677.	358.33
561.20	294.	600.80	316.	639.	337.22	678.	358.89
562.	294.44	601.	316.11	640.	337.78	678.20	359.
563.	295.	602.	316.67	640.40	338.	679.	359.44
564.	295.56	602.60	317.	641.	338.33	680.	360.
564.80	296.	603.	317.22	642.	338.89	681.	360.56
565.	296.11	604.	317.78	642.20	339.	681.80	361.
566.	296.67	604.40	318.	643.	339.44	682.	361.11
566.60	297.	605.	318.33	644.	340.	683.	361.67
567.	297.22	606.	318.89	645.	340.56	683.60	362.
568.	297.78	606.20	319.	645.80	341.	684.	362.22
568.40	298.	607.	319.44	646.	341.11	685.	362.78
569.	298.33	608.	320.	647.	341.67	685.40	363.
570.	298.89	609.	320.56	647.60	342.	686.	363.33
570.20	299.	609.80	321.	648.	342.22	687.	363.89
571.	299.44	610.	321.11	649.	342.78	687.20	364.
572.	300.	611.	321.67	649.40	343.	688.	364.44
573.	300.56	611.60	322.	650.	343.33	689.	365.
573.80	301.	612.	322.33	651.	343.89	690.	365.56
574.	301.11	613.	322.70	651.20	344.	690.80	366.
575.	301.67	613.40	323.	652.	344.44	691.	366.11
575.60	302.	614.	323.33	653.	345.	692.	366.67
576.	302.22	615.	323.89	654.	345.56	692.60	367.
577.	302.78	615.20	324.	654.80	346.	693.	367.22
577.40	303.	616.	324.44	655.	346.11	694.	367.78
578.	303.33	617.	325.	656.	346.67	694.40	368.
579.	303.89	618.	325.56	656.60	347.	695.	368.33
579.20	304.	618.80	326.	657.	347.22	696.	368.89
580.	304.44	619.	326.11	658.	347.78	696.20	369.
581.	305.	620.	326.67	658.40	348.	697.	369.44
582.	305.56	620.60	327.	659.	348.33	698.	370.
582.80	306.	621.	327.22	660.	348.89	699.	370.56
583.	306.11	622.	327.78	660.20	349.	699.80	371.
584.	306.67	622.40	328.	661.	349.44	700.	371.11
584.60	307.	623.	328.33	662.	350.	701.	371.67
585.	307.22	624.	328.89	663.	350.56	701.60	372.
586.	307.78	624.20	329.	663.80	351.	702.	372.22
586.40	308.	625.	329.44	664.	351.11	703.	372.78
587.	308.33	626.	330.	665.	351.67	703.40	373.
588.	308.89	627.	330.56	665.60	352.	704.	373.33
588.20	309.	627.80	331.	666.	352.22	705.	373.89
589.	309.44	628.	331.11	667.	352.78	705.20	374.
590.	310.	629.	331.67	667.40	353.	706.	374.44
591.	310.56	629.60	332.	668.	353.33	707.	375.
591.80	311.	630.	332.22	669.	353.89	708.	375.56
592.	311.11	631.	332.78	669.20	354.	708.80	376.
593.	311.67	631.40	333.	670.	354.44	709.	376.11
593.60	312.	632.	333.33	671.	355.	710.	376.67
594.	312.22	633.	333.89	672.	355.56	710.60	377.
595.	312.78	633.20	334.	672.80	356.	711.	377.22
595.40	313.	634.	334.44	673.	356.11	712.	377.78
596.	313.33	635.	335.	674.	356.67	712.40	378.
597.	313.89	636.	335.56	674.60	357.	713.	378.33
597.20	314.	636.80	336.	675.	357.22	714.	378.89
598.	314.44	637.	336.11	676.	357.78	714.20	379.

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales (Continued)

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
715.	379.44	**754.**	401.11	**793.**	422.78	831.20	**444.**
716.	**380.**	**755.**	401.67	793.40	**423.**	**832.**	444.44
717.	380.56	755.60	**402.**	**794.**	423.33	**833.**	**445.**
717.80	**381.**	**756.**	402.22	**795.**	423.89	**834.**	445.56
718.	381.11	**757.**	402.78	795.20	**424.**	834.80	**446.**
719.	381.67	757.40	**403.**	**796.**	424.44	**835.**	446.11
719.60	**382.**	**758.**	403.33	**797.**	**425.**	**836.**	446.67
720.	382.22	**759.**	403.89	**798.**	425.56	836.60	**447.**
721.	382.78	759.78	**404.**	798.80	**426.**	**837.**	447.22
721.40	**383.**	**760.**	404.44	**799.**	426.11	**838.**	447.78
722.	383.33	**761.**	**405.**	**800.**	426.67	838.40	**448.**
723.	383.89	**762.**	405.56	800.60	**427.**	**839.**	448.33
723.20	**384.**	762.80	**406.**	**801.**	427.22	**840.**	448.89
724.	384.44	**763.**	406.11	**802.**	427.78	840.20	**449.**
725.	**385.**	**764.**	406.67	802.40	**428.**	**841.**	449.44
726.	385.56	764.60	**407.**	**803.**	428.33	**842.**	**450.**
726.80	**386.**	**765.**	407.22	**804.**	428.89	**843.**	450.56
727.	386.11	**766.**	407.78	804.20	**429.**	843.80	**451.**
728.	386.67	766.40	**408.**	**805.**	429.44	**844.**	451.11
728.60	**387.**	**767.**	408.33	**806.**	**430.**	**845.**	451.67
729.	387.22	**768.**	408.89	**807.**	430.56	845.60	**452.**
730.	387.78	768.20	**409.**	807.80	**431.**	**846.**	452.22
730.40	**388.**	**769.**	409.44	**808.**	431.11	**847.**	452.78
731.	388.33	**770.**	**410.**	**809.**	431.67	847.40	**453.**
732.	388.89	**771.**	410.56	809.60	**432.**	**848.**	453.33
732.20	**389.**	771.80	**411.**	**810.**	432.22	**849.**	453.89
733.	389.44	**772.**	411.11	**811.**	432.78	849.20	**454.**
734.	**390.**	**773.**	411.67	811.40	**433.**	**850.**	454.44
735.	390.56	773.60	**412.**	**812.**	433.33	**851.**	**455.**
735.80	**391.**	**774.**	412.22	**813.**	433.89	**852.**	455.56
736.	391.11	**775.**	412.78	813.20	**434.**	852.80	**456.**
737.	391.67	775.40	**413.**	**814.**	434.44	**853.**	456.11
737.60	**392.**	**776.**	413.33	**815.**	435.	**854.**	456.67
738.	392.22	**777.**	413.89	**816.**	435.56	854.60	**457.**
739.	392.78	777.20	**414.**	816.80	**436.**	**855.**	457.22
739.40	**393.**	**778.**	414.44	**817.**	436.11	**856.**	457.78
740.	393.33	**779.**	**415.**	**818.**	436.67	856.40	**458.**
741.	393.89	**780.**	415.56	818.60	**437.**	**857.**	458.33
741.20	**394.**	780.80	**416.**	**819.**	437.22	**858.**	458.89
742.	394.44	**781.**	416.11	**820.**	437.78	858.20	**459.**
743.	**395.**	**782.**	416.67	820.40	**438.**	**859.**	459.44
744.	395.56	782.60	**417.**	**821.**	438.33	**860.**	**460.**
744.80	**396.**	**783.**	417.22	**822.**	438.89	**861.**	460.56
745.	396.11	**784.**	417.78	822.20	**439.**	861.80	**461.**
746.	396.67	784.40	**418.**	**823.**	439.44	**862.**	461.11
746.60	**397.**	**785.**	418.33	**824.**	**440.**	**863.**	461.67
747.	397.22	**786.**	418.89	**825.**	440.56	863.60	**462.**
748.	397.78	786.20	**419.**	825.80	**441.**	**864.**	462.22
748.40	**398.**	**787.**	419.44	**826.**	441.11	**865.**	462.78
749.	398.33	**788.**	**420.**	**827.**	441.67	865.40	**463.**
750.	398.89	**789.**	420.56	827.60	**442.**	**866.**	463.33
750.20	**399.**	789.80	**421.**	**828.**	442.22	**867.**	463.89
751.	399.44	**790.**	421.11	**829.**	442.78	867.20	**464.**
752.	**400.**	**791.**	421.67	829.40	**443.**	**868.**	464.44
753.	400.56	791.60	**422.**	**830.**	443.33	**869.**	**465.**
753.80	**401.**	**792.**	422.22	**831.**	443.89	**870.**	465.56

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales (Continued)

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
870.80	**466.**	**909.**	487.22	**948.**	508.89	**987.**	530.56
871.	466.11	**910.**	487.78	948.20	**509.**	987.80	**531.**
872.	466.67	910.40	**488.**	**949.**	509.44	**988.**	531.11
872.60	**467.**	**911.**	488.33	**950.**	**510.**	**989.**	531.67
873.	467.22	**912.**	488.89	**951.**	510.56	989.60	**532.**
874.	467.78	912.20	**489.**	951.80	**511.**	**990.**	532.22
874.40	**468.**	**913.**	489.44	**952.**	511.11	**991.**	532.78
875.	468.33	**914.**	**490.**	**953.**	511.67	991.60	**533.**
876.	468.89	**915.**	490.56	953.60	**512.**	**992.**	533.33
876.20	**469.**	915.80	**491.**	**954.**	512.22	**993.**	533.89
877.	469.44	**916.**	491.11	**955.**	512.78	993.40	**534.**
878.	**470.**	**917.**	491.67	955.40	**513.**	**994.**	534.44
879.	470.56	917.60	**492.**	**956.**	513.33	**995.**	**535.**
879.80	**471.**	**918.**	492.22	**957.**	513.89	995.20	535.56
880.	471.11	**919.**	492.78	957.20	**514.**	**996.**	**536.**
881.	471.67	919.40	**493.**	**958.**	514.44	**997.**	536.11
881.60	**472.**	**920.**	493.33	**959.**	**515.**	**998.**	536.67
882.	472.22	**921.**	493.89	**960.**	515.56	998.80	**537.**
883.	472.78	921.20	**494.**	960.80	**516.**	**999.**	537.22
883.40	**473.**	**922.**	494.44	**961.**	516.11	**1000.**	537.78
884.	473.33	**923.**	**495.**	**962.**	516.67	**1004.**	**540.**
885.	473.89	**924.**	495.56	962.60	**517.**	**1010.**	543.33
885.20	**474.**	924.80	**496.**	**963.**	517.22	**1020.**	548.89
886.	474.44	**925.**	496.11	**964.**	517.78	**1022.**	**550.**
887.	**475.**	**926.**	496.67	964.40	**518.**	**1030.**	554.44
888.	475.56	926.60	**497.**	**965.**	518.33	**1040.**	**560.**
888.80	**476.**	**927.**	497.22	**966.**	518.89	**1050.**	565.56
889.	476.11	**928.**	497.78	966.20	**519.**	**1058.**	**570.**
890.	476.67	928.40	**498.**	**967.**	519.44	**1060.**	571.11
890.60	**477.**	**929.**	498.33	**968.**	**520.**	**1070.**	576.67
891.	477.22	**930.**	498.89	**969.**	520.56	**1076.**	**580.**
892.	477.78	930.20	**499.**	969.80	**521.**	**1080.**	582.22
892.40	**478.**	**931.**	499.44	**970.**	521.11	**1090.**	587.78
893.	478.33	**932.**	**500.**	**971.**	521.67	**1094.**	**590.**
894.	478.89	**933.**	500.56	971.60	**522.**	**1100.**	593.33
894.20	**479.**	933.80	**501.**	**972.**	522.22	**1110.**	598.89
895.	479.44	**934.**	501.11	**973.**	522.78	**1112.**	**600.**
896.	**480.**	**935.**	501.67	973.40	**523.**	**1120.**	604.44
897.	480.56	935.60	**502.**	**974.**	523.33	**1130.**	**610.**
897.80	**481.**	**936.**	502.22	**975.**	523.78	**1140.**	615.56
898.	481.11	**937.**	502.78	975.20	**524.**	**1148.**	**620.**
899.	481.67	937.40	**503.**	**976.**	524.44	**1150.**	621.11
899.60	**482.**	**938.**	503.33	**977.**	**525.**	**1160.**	626.67
900.	482.22	**939.**	503.89	**978.**	525.56	**1166.**	**630.**
901.	482.78	939.20	**504.**	978.80	**526.**	**1170.**	632.22
901.40	**483.**	**940.**	504.44	**979.**	526.11	**1180.**	637.78
902.	483.33	**941.**	**505.**	**980.**	526.67	**1184.**	**640.**
903.	483.89	**942.**	505.56	980.60	**527.**	**1190.**	643.33
903.20	**484.**	942.80	**506.**	**981.**	527.22	**1200.**	648.89
904.	484.44	**943.**	506.11	**982.**	527.78	**1202.**	**650.**
905.	**485.**	**944.**	506.67	982.40	**528.**	**1210.**	654.44
906.	485.56	944.60	**507.**	**983.**	528.33	**1220.**	**660.**
906.80	**486.**	**945.**	507.22	**984.**	528.89	**1230.**	665.56
907.	486.11	**946.**	507.78	984.20	**529.**	**1238.**	**670.**
908.	486.67	946.40	**508.**	**985.**	529.44	**1240.**	671.11
908.60	**487.**	**947.**	508.33	**986.**	**530.**	**1250.**	676.67

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales (Continued)

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
1256.	680.	1640.	893.33	2030.	1110.	2420.	1326.67
1260.	682.22	1650.	898.89	2040.	1115.56	2426.	1330.
1270.	687.78	1652.	900.	2048.	1120.	2430.	1332.22
1274.	690.	1660.	904.44	2050.	1121.11	2440.	1337.78
1280.	693.33	1670.	910.	2060.	1126.67	2444.	1340.
1290.	698.89	1680.	915.56	2066.	1130.	2450.	1343.33
1292.	700.	1688.	920.	2070.	1132.22	2460.	1348.89
1300.	704.44	1690.	921.11	2080.	1137.78	2462.	1350.
1310.	710.	1700.	926.67	2084.	1140.	2470.	1354.44
1320.	715.56	1706.	930.	2090.	1143.33	2480.	1360.
1328.	720.	1710.	932.22	2100.	1148.89	2490.	1365.56
1330.	721.11	1720.	937.78	2102.	1150.	2498.	1370.
1340.	726.67	1724.	940.	2110.	1154.44	2500.	1371.11
1346.	730.	1730.	943.33	2120.	1160.	2510.	1376.67
1350.	732.22	1740.	948.89	2130.	1165.56	2516.	1380.
1360.	737.78	1742.	950.	2138.	1170.	2520.	1382.22
1364.	740.	1750.	954.44	2140.	1171.11	2530.	1387.78
1370.	743.33	1760.	960.	2150.	1176.67	2534.	1390.
1380.	748.89	1770.	965.56	2156.	1180.	2540.	1393.33
1382.	750.	1778.	970.	2160.	1182.22	2550.	1398.89
1390.	754.44	1780.	971.11	2170.	1187.78	2552.	1400.
1400.	760.	1790.	976.67	2174.	1190.	2560.	1404.44
1410.	765.56	1796.	980.	2180.	1193.33	2570.	1410.
1418.	770.	1800.	982.22	2190.	1198.89	2580.	1415.56
1420.	771.11	1810.	987.78	2192.	1200.	2588.	1420.
1430.	776.67	1814.	990.	2200.	1204.44	2590.	1421.11
1436.	780.	1820.	993.33	2210.	1210.	2600.	1426.67
1440.	782.22	1830.	998.89	2220.	1215.56	2606.	1430.
1450.	787.78	1832.	1000.	2228.	1220.	2610.	1432.22
1454.	790.	1840.	1004.44	2230.	1221.11	2620.	1437.78
1460.	793.33	1850.	1010.	2240.	1226.67	2624.	1440.
1470.	798.89	1860.	1015.56	2246.	1230.	2630.	1443.33
1472.	800.	1868.	1020.	2250.	1232.22	2640.	1448.89
1480.	804.44	1870.	1021.11	2260.	1237.78	2642.	1450.
1490.	810.	1880.	1026.67	2264.	1240.	2650.	1454.44
1500.	815.56	1886.	1030.	2270.	1243.33	2660.	1460.
1508.	820.	1890.	1032.22	2280.	1248.89	2670.	1465.56
1510.	821.11	1900.	1037.78	2282.	1250.	2678.	1470.
1520.	826.67	1904.	1040.	2290.	1254.44	2680.	1471.11
1526.	830.	1910.	1043.33	2300.	1260.	2690.	1476.67
1530.	832.22	1920.	1048.89	2310.	1265.56	2696.	1480.
1540.	837.78	1922.	1050.	2318.	1270.	2700.	1482.22
1544.	840.	1930.	1054.44	2320.	1271.11	2710.	1487.78
1550.	843.33	1940.	1060.	2330.	1276.67	2714.	1490.
1560.	848.89	1950.	1065.56	2336.	1280.	2720.	1493.33
1562.	850.	1958.	1070.	2340.	1282.22	2730.	1498.89
1570.	854.44	1960.	1071.11	2350.	1287.78	2732.	1500.
1580.	860.	1970.	1076.67	2354.	1290.	2740.	1504.44
1590.	865.56	1976.	1080.	2360.	1293.33	2750.	1510.
1598.	870.	1980.	1082.22	2370.	1298.89	2760.	1515.56
1600.	871.11	1990.	1087.78	2372.	1300.	2768.	1520.
1610.	876.67	1994.	1090.	2380.	1304.44	2770.	1521.11
1616.	880.	2000.	1093.33	2390.	1310.	2780.	1526.67
1620.	882.22	2010.	1098.89	2400.	1315.56	2786.	1530.
1630.	887.78	2012.	1100.	2408.	1320.	2790.	1532.22
1634.	890.	2020.	1104.44	2410.	1321.11	2800.	1537.78

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales (Continued)

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
2804.	1540.	3010.	1654.44	3220.	1771.11	3430.	1887.78
2810.	1543.33	3020.	1660.	3230.	1776.67	3434.	1890.
2820.	1548.89	3030.	1665.56	3236.	1780.	3440.	1893.33
2822.	1550.	3038.	1670.	3240.	1782.22	3450.	1898.89
2830.	1554.44	3040.	1671.11	3250.	1787.78	3452.	1900.
2840.	1560.	3050.	1676.67	3254.	1790.	3460.	1904.44
2850.	1565.56	3056.	1680.	3260.	1793.33	3470.	1910.
2858.	1570.	3060.	1682.22	3270.	1798.89	3480.	1915.56
2860.	1571.11	3070.	1687.78	3272.	1800.	3488.	1920.
2870.	1576.67	3074.	1690.	3280.	1804.44	3490.	1921.11
2876.	1580.	3080.	1693.33	3290.	1810.	3500.	1926.67
2880.	1582.22	3090.	1698.89	3300.	1815.56	3506.	1930.
2890.	1587.78	3092.	1700.	3308.	1820.	3510.	1932.22
2894.	1590.	3100.	1704.44	3310.	1821.11	3520.	1937.78
2900.	1593.33	3110.	1710.	3320.	1826.67	3524.	1940.
2910.	1598.89	3120.	1715.56	3326.	1830.	3530.	1943.33
2912.	1600.	3128.	1720.	3330.	1832.22	3540.	1948.89
2920.	1604.44	3130.	1721.11	3340.	1837.78	3542.	1950.
2930.	1610.	3140.	1726.67	3344.	1840.	3550.	1954.44
2940.	1615.56	3146.	1730.	3350.	1843.33	3560.	1960.
2948.	1620.	3150.	1732.22	3360.	1848.89	3570.	1965.56
2950.	1621.11	3160.	1737.78	3362.	1850.	3578.	1970.
2960.	1626.67	3164.	1740.	3370.	1854.44	3580.	1971.11
2966.	1630.	3170.	1743.33	3380.	1860.	3590.	1976.67
2970.	1632.22	3180.	1748.89	3390.	1865.56	3596.	1980.
2980.	1637.78	3182.	1750.	3398.	1870.	3600.	1982.22
2984.	1640.	3190.	1754.44	3400.	1871.11	3610.	1987.78
2990.	1643.33	3200.	1760.	3410.	1876.67	3614.	1990.
3000.	1648.89	3210.	1765.56	3416.	1880.	3620.	1993.33
3002.	1650.	3218.	1770.	3420.	1882.22	3630.	1998.89

SPECIFIC GRAVITY EQUIVALENTS FOR DEGREES BAUMÉ FOR LIQUIDS HEAVIER THAN WATER

Table adopted by the U. S. Bureau of Standards from the formula:

$$\text{Degrees Baumé} = 145 - \frac{145}{\text{*Specific Gravity } \frac{60^\circ}{60^\circ}\text{F.}}$$

Baumé	Specific Gravity	Lbs. per Gallon	Baumé	Specific Gravity	Lbs. per Gallon	Baumé	Specific Gravity	Lbs. per Gallon
0	1.0000	8.33	26	1.2185	10.16	52	1.5591	12.99
1	1.0069	8.38	27	1.2288	10.24	53	1.5761	13.13
2	1.0140	8.46	28	1.2393	10.32	54	1.5934	13.27
3	1.0211	8.51	29	1.2500	10.41	55	1.6111	13.42
4	1.0284	8.56	30	1.2609	10.51	56	1.6292	13.57
5	1.0357	8.63	31	1.2719	10.59	57	1.6477	13.72
6	1.0432	8.69	32	1.2832	10.69	58	1.6667	13.87
7	1.0507	8.75	33	1.2946	10.78	59	1.6860	14.04
8	1.0584	8.81	34	1.3063	10.84	60	1.7059	14.21
9	1.0662	8.88	35	1.3182	10.98	61	1.7262	14.38
10	1.0741	8.94	36	1.3303	11.09	62	1.7470	14.55
11	1.0821	9.01	37	1.3426	11.18	63	1.7683	14.72
12	1.0902	9.09	38	1.3551	11.29	64	1.7901	14.91
13	1.0985	9.15	39	1.3679	11.39	65	1.8125	15.10
14	1.1069	9.21	40	1.3810	11.51	66	1.8354	15.29
15	1.1154	9.29	41	1.3942	11.61	67	1.8590	15.48
16	1.1240	9.36	42	1.4078	11.72	68	1.8831	15.68
17	1.1328	9.43	43	1.4216	11.84	69	1.9079	15.89
18	1.1417	9.51	44	1.4356	11.96	70	1.9333	16.10
19	1.1508	9.59	45	1.4500	12.08	71	1.9595	16.32
20	1.1600	9.67	46	1.4646	12.21	72	1.9864	16.55
21	1.1694	9.74	47	1.4796	12.33	73	2.0139	16.78
22	1.1789	9.81	48	1.4948	12.46	74	2.0423	17.01
23	1.1885	9.90	49	1.5104	12.58	75	2.0714	17.25
24	1.1983	9.99	50	1.5263	12.72			
25	1.2083	10.07	51	1.5426	12.85			

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*All densities taken at temperature of 60° F. and referred to distilled water at 60° F. as standard.

SPECIFIC GRAVITY EQUIVALENTS FOR DEGREES BAUMÉ FOR LIQUIDS LIGHTER THAN WATER

Table adopted by the U. S. Bureau of Standards from the formula:

$$\text{Degrees Baumé} = \frac{140}{{}^{*}\text{Specific Gravity } \frac{60^\circ}{60^\circ}\text{F.}} - 130$$

Baumé	Specific Gravity	Lbs. per Gallon	Baumé	Specific Gravity	Lbs. per Gallon	Baumé	Specific Gravity	Lbs. per Gallon
10	1.0000	8.33	44	0.8046	6.70	78	0.6731	5.60
11	0.9929	8.27	45	0.8000	6.66	79	0.6699	5.58
12	0.9859	8.21	46	0.7955	6.63	80	0.6667	5.55
13	0.9790	8.16	47	0.7910	6.59	81	0.6635	5.52
14	0.9722	8.10	48	0.7865	6.55	82	0.6604	5.50
15	0.9655	8.04	49	0.7821	6.52	83	0.6573	5.48
16	0.9589	7.99	50	0.7778	6.48	84	0.6542	5.45
17	0.9524	7.93	51	0.7735	6.44	85	0.6512	5.42
18	0.9459	7.88	52	0.7692	6.41	86	0.6481	5.40
19	0.9396	7.83	53	0.7650	6.37	87	0.6452	5.38
20	0.9333	7.78	54	0.7609	6.34	88	0.6422	5.36
21	0.9272	7.72	55	0.7568	6.30	89	0.6393	5.33
22	0.9211	7.67	56	0.7527	6.27	90	0.6364	5.30
23	0.9150	7.62	57	0.7487	6.24	91	0.6335	5.28
24	0.9091	7.57	58	0.7447	6.20	92	0.6306	5.25
25	0.9032	7.53	59	0.7407	6.17	93	0.6278	5.23
26	0.8974	7.48	60	0.7368	6.14	94	0.6250	5.21
27	0.8917	7.43	61	0.7330	6.11	95	0.6222	5.18
28	0.8861	7.38	62	0.7292	6.07	96	0.6195	5.16
29	0.8805	7.34	63	0.7254	6.04	97	0.6167	5.14
30	0.8750	7.29	64	0.7216	6.01	98	0.6140	5.11
31	0.8696	7.24	65	0.7179	5.98	99	0.6114	5.09
32	0.8642	7.20	66	0.7143	5.95	100	0.6087	5.07
33	0.8589	7.15	67	0.7107	5.92	101	0.6061	5.05
34	0.8537	7.11	68	0.7071	5.89	102	0.6034	5.03
35	0.8485	7.07	69	0.7035	5.86	103	0.6009	5.00
36	0.8434	7.03	70	0.7000	5.83	104	0.5983	4.98
37	0.8383	6.98	71	0.6965	5.80	105	0.5957	4.96
38	0.8333	6.94	72	0.6931	5.78	106	0.5932	4.94
39	0.8284	6.90	73	0.6897	5.75	107	0.5907	4.92
40	0.8235	6.86	74	0.6863	5.72	108	0.5882	4.90
41	0.8187	6.82	75	0.6829	5.69	109	0.5858	4.88
42	0.8140	6.78	76	0.6796	5.66	110	0.5833	4.86
43	0.8092	6.74	77	0.6763	5.63			

***All densities taken at temperature of 60° F. and referred to distilled water at 60° F. as standard.**

SULPHURIC ACID

(W. C. Ferguson and H. P. Talbot)

Adopted by the Manufacturing Chemists' Association of the U. S., 1904

°Beaumé	Sp. Gr. $\frac{60° F.}{60° F.}$	% H_2SO_4
0	1.0000	0.00
1	1.0069	1.02
2	1.0140	2.08
3	1.0211	3.13
4	1.0284	4.21
5	1.0357	5.28
6	1.0432	6.37
7	1.0507	7.45
8	1.0584	8.55
9	1.0662	9.66
10	1.0741	10.77
11	1.0821	11.89
12	1.0902	13.01
13	1.0985	14.13
14	1.1069	15.25
15	1.1154	16.38
16	1.1240	17.53
17	1.1328	18.71
18	1.1417	19.89
19	1.1508	21.07
20	1.1600	22.25
21	1.1694	23.43
22	1.1789	24.61
23	1.1885	25.81
24	1.1983	27.03
25	1.2083	28.28
26	1.2185	29.53
27	1.2288	30.79
28	1.2393	32.05
29	1.2500	33.33
30	1.2609	34.63
31	1.2719	35.93
32	1.2832	37.26
33	1.2946	38.58
34	1.3063	39.92
35	1.3182	41.27
36	1.3303	42.63
37	1.3426	43.99
38	1.3551	45.35
39	1.3679	46.72
40	1.3810	48.10
41	1.3942	49.47
42	1.4078	50.87
43	1.4216	52.26
44	1.4356	53.66
45	1.4500	55.07
46	1.4646	56.48
47	1.4796	57.90
48	1.4948	59.32
49	1.5104	60.75
50	1.5263	62.18
51	1.5422	63.36
52	1.5591	65.61
53	1.5761	66.63
54	1.5934	68.13
55	1.6111	69.65
56	1.6292	71.17
57	1.6477	72.75
58	1.6667	74.36
59	1.6860	75.99
60	1.7059	77.67
61	1.7262	79.43
62	1.7470	81.30
63	1.7683	83.34
64	1.7901	85.86
64¼	1.7957	86.33
64½	1.8012	87.04
64¾	1.8068	87.81
65	1.8125	88.65
65¼	1.8182	89.55
65½	1.8239	90.60
65¾	1.8297	91.80
66	1.8354	93.19

Allowance for Temperatures

At 10° Bé. correction of .029° Bé. or .00023 Sp. Gr. for every 1° F.
At 20° Bé. correction of .036° Bé. or .00034 Sp. Gr. for every 1° F.
At 30° Bé. correction of .035° Bé. or .00039 Sp. Gr. for every 1° F.
At 40° Bé. correction of .031° Bé. or .00041 Sp. Gr. for every 1° F.
At 50° Bé. correction of .028° Bé. or .00045 Sp. Gr. for every 1° F.
At 60° Bé. correction of .026° Bé. or .00053 Sp. Gr. for every 1° F.
At 63° Bé. correction of .026° Bé. or .00057 Sp. Gr. for every 1° F.
At 66° Bé. correction of .0235° Be. or .00054 Sp. Gr. for every 1° F.

For temperatures above 60° F., the correction is added to the observed indication; below 60° F., subtracted.

FUMING SULPHURIC ACID

Free SO_3, Total SO_3, and Equivalent Values in Terms of 100%, 98% and 93.19% H_2SO_4

ACTUAL COMPOSITION		EQUIVALENTS			
Free SO_3 %	H_2SO_4 %	Total SO_3	100% H_2SO_4	98% H_2SO_4	93.19% H_2SO_4 66° Bé.
0	100	81.63	100.00	102.04	107.31
1	99	81.62	100.23	102.27	107.55
2	98	82.00	100.45	102.50	107.79
3	97	82.18	100.67	102.73	108.03
4	96	82.37	100.90	102.96	108.28
5	95	82.55	101.13	103.19	108.52
6	94	82.73	101.35	103.42	108.76
7	93	82.92	101.58	103.65	109.00
8	92	83.10	101.80	103.88	109.24
9	91	83.29	102.03	104.11	109.48
10	90	83.47	102.25	104.34	109.72
11	89	83.65	102.47	104.57	109.96
12	88	83.84	102.70	104.80	110.21
13	87	84.02	102.92	105.03	110.45
14	86	84.20	103.15	105.26	110.69
15	85	84.39	103.38	105.49	110.93
16	84	84.57	103.60	105.71	111.17
17	83	84.75	103.82	105.94	111.41
18	82	84.94	104.05	106.17	111.65
19	81	85.12	104.27	106.40	111.90
20	80	85.31	104.50	106.63	112.14
21	79	85.49	104.73	106.86	112.38
22	78	85.67	104.95	107.09	112.62
23	77	85.86	105.18	107.32	112.86
24	76	86.04	105.40	107.55	113.10
25	75	86.22	105.62	107.78	113.34
26	74	86.41	105.85	108.01	113.59
27	73	86.59	106.07	108.24	113.83
28	72	86.78	106.30	108.47	114.07
29	71	86.96	106.53	108.70	114.31
30	70	87.14	106.75	108.93	114.55
31	69	87.33	106.98	109.16	114.79
32	68	87.51	107.20	109.39	115.03
33	67	87.69	107.42	109.62	115.28
34	66	87.88	107.65	109.85	115.52
35	65	88.06	107.87	110.08	115.76
36	64	88.24	108.10	110.31	116.00
37	63	88.43	108.33	110.54	116.24
38	62	88.61	108.55	110.76	116.48
39	61	88.80	108.78	110.99	116.73
40	60	88.98	109.00	111.22	116.97
41	59	89.16	109.22	111.45	117.21
42	58	89.35	109.45	111.68	117.45
43	57	89.53	109.67	111.91	117.69
44	56	89.71	109.90	112.14	117.93
45	55	89.90	110.13	112.37	118.17
46	54	90.08	110.35	112.60	118.41
47	53	90.27	110.58	112.83	118.66
48	52	90.45	110.80	113.06	118.90
49	51	90.63	111.02	113.29	119.14

FUMING SULPHURIC ACID (Continued)

Free SO_3, Total SO_3, and Equivalent Values in Terms of 100%, 98% and 93.19% H_2SO_4

Actual Composition		Equivalents			
Free SO_3 %	H_2SO_4 %	Total SO_3	100% H_2SO_4	98% H_2SO_4	93.19% H_2SO_4 66° Bé.
50	50	90.82	111.25	113.52	119.38
51	49	91.00	111.48	113.75	119.62
52	48	91.18	111.70	113.98	119.86
53	47	91.37	111.93	114.21	120.11
54	46	91.55	112.15	114.44	120.35
55	45	91.73	112.37	114.67	120.59
56	44	91.92	112.60	114.90	120.83
57	43	92.10	112.83	115.13	121.07
58	42	92.29	113.05	115.36	121.31
59	41	92.47	113.28	115.59	121.55
60	40	92.65	113.50	115.82	121.79
61	39	92.84	113.73	116.05	122.04
62	38	93.02	113.95	116.28	122.28
63	37	93.20	114.17	116.51	122.52
64	36	93.39	114.40	116.74	122.76
65	35	93.57	114.62	116.96	123.00
66	34	93.76	114.85	117.19	123.24
67	33	93.94	115.08	117.42	123.49
68	32	94.12	115.30	117.65	123.73
69	31	94.31	115.53	117.88	123.97
70	30	94.49	115.75	118.11	124.21
71	29	94.67	115.97	118.34	124.45
72	28	94.86	116.20	118.57	124.69
73	27	95.04	116.42	118.80	124.93
74	26	95.22	116.65	119.03	125.18
75	25	95.41	116.88	119.26	125.42
76	24	94.59	117.10	119.49	125.66
77	23	95.78	117.33	119.72	125.90
78	22	95.96	117.55	119.95	126.14
79	21	96.14	117.77	120.18	126.38
80	20	96.33	118.00	120.41	126.62
81	19	96.51	118.22	120.64	126.86
82	18	95.69	118.45	120.87	127.11
83	17	96.88	118.68	121.10	127.35
84	16	97.06	118.90	121.23	127.59
85	15	97.43	119.13	121.56	127.83
86	14	97.61	119.35	121.79	128.07
87	13	97.80	119.57	122.02	128.31
88	12	97.98	119.80	122.25	128.56
89	11	....	120.03	122.48	128.80
90	10	98.16	120.25	122.70	129.04
91	9	98.35	120.48	122.93	129.28
92	8	98.53	120.70	123.16	129.52
93	7	98.71	120.92	123.39	129.76
94	6	98.90	121.15	123.62	130.00
95	5	99.08	121.37	123.85	130.25
96	4	99.27	121.60	124.08	130.49
97	3	99.45	121.83	124.31	130.73
98	2	99.63	122.05	124.54	130.97
99	1	99.82	122.28	124.77	131.21
100	0	100.00	122.50	125.00	131.45

NITRIC ACID

(W. C. Ferguson)

Adopted by the Manufacturing Chemists' Association of the U. S. 1904,

° Beaumé	Sp. Gr. $\frac{60° F.}{60° F.}$	% HNO_3	° Beaumé	Sp. Gr. $\frac{60° F.}{60° F.}$	% HNO_3
10.00	1.0741	12.86	34.00	1.3063	48.42
10.50	1.0781	13.49	34.50	1.3122	49.35
11.00	1.0821	14.13	35.00	1.3182	50.32
11.50	1.0861	14.76	35.50	1.3242	51.30
12.00	1.0902	15.41	36.00	1.3303	52.30
12.50	1.0943	16.05	36.50	1.3364	53.32
13.00	1.0985	16.72	37.00	1.3426	54.36
13.50	1.1027	17.38	37.50	1.3488	55.43
14.00	1.1069	18.04	38.00	1.3551	56.52
14.50	1.1111	18.70	38.50	1.3615	57.65
15.00	1.1154	19.36	39.00	1.3679	58.82
15.50	1.1197	20.02	39.50	1.3744	60.06
16.00	1.1240	20.69	40.00	1.3810	61.38
16.50	1.1284	21.36	40.25	1.3843	62.07
17.00	1.1328	22.04	40.50	1.3876	62.77
17.50	1.1373	22.74	40.75	1.3909	63.48
18.00	1.1417	23.42	41.00	1.3942	64.20
18.50	1.1462	24.11	41.25	1.3976	64.93
19.00	1.1508	24.82	41.50	1.4010	65.67
19.50	1.1554	25.53	41.75	1.4044	66.42
20.00	1.1600	26.24	42.00	1.4078	67.18
20.50	1.1647	26.96	42.25	1.4112	67.95
21.00	1.1694	27.67	42.50	1.4146	68.73
21.50	1.1741	28.36	42.75	1.4181	60.52
22.00	1.1789	29.07	43.00	1.4216	70.33
22.50	1.1837	29.78	43.25	1.4251	71.15
23.00	1.1885	30.49	43.50	1.4286	71.98
23.50	1.1934	31.21	43.75	1.4321	72.82
24.00	1.1983	31.94	44.00	1.4356	73.67
24.50	1.2033	32.68	44.25	1.4392	74.53
25.00	1.2083	33.42	44.50	1.4428	75.40
25.50	1.2134	34.17	44.75	1.4464	76.28
26.00	1.2185	34.94	45.00	1.4500	77.17
26.50	1.2236	35.70	45.25	1.4536	78.07
27.00	1.2288	36.48	45.50	1.4573	79.03
27.50	1.2340	37.26	45.75	1.4610	80.04
28.00	1.2393	38.06	46.00	1.4646	81.08
28.50	1.2446	38.85	46.25	1.4684	82.18
29.00	1.2500	39.66	46.50	1.4721	83.33
29.50	1.2554	40.47	46.75	1.4758	84.48
30.00	1.2609	41.30	47.00	1.4796	85.70
30.50	1.2664	42.14	47.25	1.4834	86.98
31.00	1.2719	43.00	47.50	1.4872	88.32
31.50	1.2775	43.89	47.75	1.4910	89.76
32.00	1.2832	44.78	48.00	1.4948	91.35
32.50	1.2889	45.68	48.25	1.4987	93.13
33.00	1.2946	46.58	48.50	1.5026	95.11
33.50	1.3004	47.49			

NITRIC ACID (Continued)

Allowance for Temperature

At from 10° to 20°	Bé. correction of 1/30° Bé. or .00029 Sp. Gr. for every 1° F.
At from 20° to 30°	Bé. correction of 1/23° Bé. or .00044 Sp. Gr. for every 1° F.
At from 30° to 40°	Bé. correction of 1/20° Bé. or .00060 Sp. Gr. for every 1° F.
At from 40° to 48.5°	Bé. correction of 1/17° Bé. or .00084 Sp. Gr. for every 1°F.

HYDROCHLORIC ACID

(W. C. Ferguson)

Adopted by the Manufacturing Chemists' Association of the U. S., 1903

° Beaumé	Sp. Gr. $\frac{60° F.}{60° F.}$	% HCl.	° Beaumé	Sp. Gr. $\frac{60° F.}{60° F.}$	% HCl.
1.00	1.0069	1.40	18.70	1.1480	29.13
2.00	1.0140	2.82	18.80	1.1489	29.30
3.00	1.0211	4.25	18.90	1.1498	29.48
4.00	1.0284	5.69	19.00	1.1508	29.65
5.00	1.0357	7.15	19.10	1.1517	29.83
6.00	1.0432	8.64	19.20	1.1526	30.00
7.00	1.0507	10.17	19.30	1.1535	30.18
8.00	1.0584	11.71	19.40	1.1544	30.35
9.00	1.0662	13.26	19.50	1.1554	30.53
10.00	1.0741	14.83	19.60	1.1563	30.71
10.50	1.0781	15.62	19.70	1.1572	30.90
11.00	1.0821	16.41	19.80	1.1581	31.08
11.50	1.0861	17.21	19.90	1.1590	31.27
12.00	1.0902	18.01	20.00	1.1600	31.45
12.50	1.0943	18.82	20.10	1.1609	31.64
12.75	1.0964	19.22	20.20	1.1619	31.82
13.00	1.0985	19.63	20.30	1.1628	32.01
13.25	1.1006	20.04	20.40	1.1637	32.19
13.50	1.1027	20.45	20.50	1.1647	32.38
13.75	1.1048	20.86	20.60	1.1656	32.56
14.00	1.1069	21.27	20.70	1.1666	32.75
14.25	1.1090	21.68	20.80	1.1675	32.93
14.50	1.1111	22.09	20.90	1.1684	32.12
14.75	1.1132	22.50	21.00	1.1694	33.31
15.00	1.1154	22.92	21.10	1.1703	33.50
15.25	1.1176	23.33	21.20	1.1713	33.69
15.50	1.1197	23.75	21.30	1.1722	33.88
15.75	1.1219	24.16	21.40	1.1732	34.07
16.00	1.1240	24.57	21.50	1.1741	34.26
16.10	1.1248	24.73	21.60	1.1751	34.45
16.20	1.1256	24.90	21.70	1.1760	34.64
16.30	1.1265	25.06	21.80	1.1770	34.83

HYDROCHLORIC ACID (Continued)

° Beaumé	Sp. Gr. $\frac{60° F.}{60° F.}$	% HCl.	° Beaumé	Sp. Gr. $\frac{60° F.}{60° F.}$	% HCl.
16.40	1.1274	25.23	21.90	1.1779	35.02
16.50	1.1283	25.39	22.00	1.1789	35.21
16.60	1.1292	25.56	22.10	1.1798	35.40
16.70	1.1301	25.72	22.20	1.1808	35.59
16.80	1.1310	25.89	22.30	1.1817	35.78
16.90	1.1319	26.05	22.40	1.1827	35.97
17.00	1.1328	26.22	22.50	1.1836	36.16
17.10	1.1336	26.39	22.60	1.1846	36.35
17.20	1.1345	26.56	22.70	1.1856	36.54
17.30	1.1354	26.73	22.80	1.1866	36.73
17.40	1.1363	26.90	22.90	1.1875	36.93
17.50	1.1372	27.07	23.00	1.1885	37.14
17.60	1.1381	27.24	23.10	1.1895	37.36
17.70	1.1390	27.41	23.20	1.1904	37.58
17.80	1.1399	27.58	23.30	1.1914	37.80
17.90	1.1408	27.75	23.40	1.1924	38.03
18.00	1.1417	27.92	23.50	1.1934	38.26
18.10	1.1426	28.09	23.60	1.1944	38.49
18.20	1.1435	28.26	23.70	1.1953	38.72
18.30	1.1444	28.44	23.80	1.1963	38.95
18.40	1.1453	28.61	23.90	1.1973	39.18
18.50	1.1462	28.78	24.00	1.1983	39.41
18.60	1.1471	28.95	24.10	1.1993	39.64

Allowance for Temperature

At 10° to 15° Bé. correction of $\frac{1}{40}$° Bé. or .0002 Sp. Gr. for every 1° F.

At 10° to 22° Bé. correction of $\frac{1}{30}$° Bé. or .0003 Sp. Gr. for every 1° F.

At 22° to 25° Bé. correction of $\frac{1}{28}$° Bé. or .00035 Sp. Gr. for every 1° F.

DENSITY OF SOLUTIONS OF SODIUM HYDROXIDE OF VARYING CONCENTRATION AT 15°C.

(Lunge)

Lbs. per Cu. Ft.	Specific Gravity	Degrees Baumé	Na_2O Per Cent	NaOH Per Cent	Grams per Liter	
					Na_2O	NaOH
62.81	1.007	1.0	0.47	0.61	4	6
63.24	1.014	2.0	0.93	1.20	9	12
63.74	1.022	3.1	1.55	2.00	16	21
64.18	1.029	4.1	2.10	2.70	22	28
64.62	1.036	5.1	2.60	3.35	27	35
65.18	1.045	6.2	3.10	4.00	32	42
65.61	1.052	7.2	3.60	5.64	38	49
66.11	1.060	8.2	4.10	5.29	43	56
66.55	1.067	9.1	4.55	5.87	49	63
67.05	1.075	10.1	5.08	6.55	55	70
67.55	1.083	11.1	5.67	7.31	61	79
68.05	1.091	12.1	6.20	8.00	68	87
68.61	1.100	13.2	6.73	8.68	74	95
69.11	1.108	14.1	7.30	9.42	81	104
69.61	1.116	15.1	7.80	10.06	87	112
70.17	1.125	16.1	8.50	10.97	96	123
70.73	1.134	17.1	9.18	11.84	104	134
71.23	1.142	18.0	9.80	12.64	112	144
71.85	1.152	19.1	10.50	13.55	121	156
72.47	1.162	20.2	11.14	14.37	129	167
73.04	1.171	21.2	11.73	15.13	137	177
73.60	1.180	22.1	12.33	15.91	146	188
74.22	1.190	23.1	13.00	16.77	155	200
74.84	1.200	24.2	13.70	17.67	164	212
75.47	1.210	25.2	14.40	18.58	174	225
76.09	1.220	26.1	15.18	19.58	185	239
76.78	1.231	27.2	15.96	20.59	196	253
77.40	1.241	28.2	16.76	21.42	208	266
78.09	1.252	29.2	17.55	22.64	220	283
78.77	1.263	30.2	18.35	23.67	232	299
79.46	1.274	31.2	19.23	24.81	245	316
80.15	1.285	32.2	20.00	25.80	257	332
80.89	1.297	33.2	20.80	26.83	270	348
81.58	1.308	34.1	21.55	27.80	282	364
82.33	1.320	35.2	22.35	28.83	295	381
83.08	1.332	36.1	23.20	29.93	309	399
83.89	1.345	37.2	24.20	31.22	326	420
84.64	1.357	38.1	25.17	32.47	342	441
85.45	1.370	39.2	26.12	33.69	359	462
86.26	1.383	40.2	27.10	34.96	375	483
87.13	1.397	41.2	28.10	36.25	392	506
87.94	1.410	42.2	29.05	37.47	410	528
88.81	1.424	43.2	30.08	38.80	428	553
89.69	1.438	44.2	31.00	39.99	446	575
90.62	1.453	45.2	32.10	41.41	466	602
91.56	1.468	46.2	33.20	42.83	487	629
92.49	1.483	47.2	34.40	44.38	510	658
93.43	1.498	48.2	35.70	46.15	535	691
94.43	1.514	49.2	36.90	47.60	559	721
95.43	1.530	50.2	38.00	49.02	581	750

AQUA AMMONIA

(W. C. Ferguson)

Adopted by the Manufacturing Chemists' Association of the United States

Be°	Sp. Gr.	$\%NH_3$	Be°	Sp. Gr.	$\%NH_3$	Be°	Sp. Gr.	$\%NH_3$
10.00	1.0000	.00	16.50	.9556	11.18	23.00	.9150	23.52
10.25	.9982	.40	16.75	.9540	11.64	23.25	.9135	24.01
10.50	.9964	.80	17.00	.9524	12.10	23.50	.9121	24.50
10.75	.9947	1.21	17.25	.9508	12.56	23.75	.9106	24.99
11.00	.9929	1.62	17.50	.9492	13.02	24.00	.9091	25.48
11.25	.9912	2.04	17.75	.9475	13.49	24.25	.9076	25.97
11.50	.9894	2.46	18.00	.9459	13.96	24.50	.9061	26.46
11.75	.9876	2.88	18.25	.9444	14.43	24.75	.9047	26.95
12.00	.9859	3.30	18.50	.9428	14.90	25.00	.9032	27.44
12.25	.9842	3.73	18.75	.9412	15.37	25.25	.9018	27.93
12.50	.9825	4.16	19.00	.9396	15.84	25.50	.9003	28.42
12.75	.9807	4.59	19.25	.9380	16.32	25.75	.8989	28.91
13.00	.9790	5.02	19.50	.9365	16.80	26.00	.8974	29.40
13.25	.9773	5.45	19.75	.9349	17.28	26.25	.8960	29.89
13.50	.9756	5.88	20.00	.9333	17.76	26.50	.8946	30.38
13.75	.9739	6.31	20.25	.9318	18.24	26.75	.8931	30.87
14.00	.9722	6.74	20.50	.9302	18.72	27.00	.8917	31.36
14.25	.9705	7.17	20.75	.9287	19.20	27.25	.8903	31.85
14.50	.9689	7.61	21.00	.9272	19.68	27.50	.8889	32.34
14.75	.9672	8.05	21.25	.9256	20.16	27.75	.8875	32.83
15.00	.9655	8.49	21.50	.9241	20.64	28.00	.8861	33.32
15.25	.9639	8.93	21.75	.9226	21.12	28.25	.8847	33.81
15.50	.9622	9.38	22.00	.9211	21.60	28.50	.8833	34.30
15.75	.9605	9.83	22.25	.9195	22.08	28.75	.8819	34.79
16.00	.9589	10.28	22.50	.9180	22.56	29.00	.8805	35.28
16.25	.9573	10.73	22.75	.9165	23.04			

Specific gravity determinations were made at 60° F., compared with water at 60° F.

From the specific gravities the correponding degrees Baumé were calculated by the following formula:

$$\text{Baumé} = \frac{140}{\text{Sp. Gr.}} - 130$$

Baumé Hydrometers for use with this table must be graduated by the above formula, which formula should always be printed on the scale.

Atomic weights from F. W. Clarke's table of 1901. O=16.

Allowance for temperature.—The coefficient of expansion for Ammonia Solutions, varying with the temperature correction, must be applied according to the following table:

	Corrections to be added for each degree below 60° F.		Corrections to be subtracted for each degree above 60° F.			
Degrees Baumé	40° F.	50° F.	70° F.	80° F.	90° F.	100° F.
14°	.015° Bé.	.017° Bé.	.020° Bé.	.022° Bé.	.024° Bé.	.026° Bé.
16°	.021 "	.023 "	.026 "	.028 "	.030 "	.032 "
18°	.027 "	.029 "	.031 "	.033 "	.035 "	.037 "
20°	.033 "	.036 "	.037 "	.038 "	.040 "	.042 "
22°	.039 "	.042 "	.043 "	.045 "	.047 "	
26°	.053 "	.057 "	.057 "	.059 "		

ACETIC ACID AT 15° C.

(Oudemans)

Specific Gravity	Per Cent $H.C_2H_3O_2$	Specific Gravity	Per Cent $H.C_2H_3O_2$	Specific Gravity	Per Cent $H.C_2H_3O_2$	Specific Gravity	Per Cent $H.C_2H_3O_2$
0.9992	0	1.0363	26	1.0623	51	1.0747	76
1.0007	1	1.0375	27	1.0631	52	1.0748	77
1.0022	2	1.0388	28	1.0638	53	1.0748	78
1.0037	3	1.0400	29	1.0646	54	1.0748	79
1.0052	4	1.0412	30	1.0653	55	1.0748	80
1.0067	5	1.0424	31	1.0660	56	1.0747	81
1.0083	6	1.0436	32	1.0666	57	1.0746	82
1.0098	7	1.0447	33	1.0673	58	1.0744	83
1.0113	8	1.0459	34	1.0679	59	1.0742	84
1.0127	9	1.0470	35	1.0685	60	1.0739	85
1.0142	10	1.0481	36	1.0691	61	1.0736	86
1.0157	11	1.0492	37	1.0697	62	1.0731	87
1.0171	12	1.0502	38	1.0702	63	1.0726	88
1.0185	13	1.0513	39	1.0707	64	1.0720	89
1.0200	14	1.0523	40	1.0712	65	1.0713	90
1.0214	15	1.0533	41	1.0717	66	1.0705	91
1.0228	16	1.0543	42	1.0721	67	1.0696	92
1.0242	17	1.0552	43	1.0725	68	1.0686	93
1.0256	18	1.0562	44	1.0729	69	1.0674	94
1.0270	19	1.0571	45	1.0733	70	1.0660	95
1.0284	20	1.0580	46	1.0737	71	1.0644	96
1.0298	21	1.0589	47	1.0740	72	1.0625	97
1.0311	22	1.0598	48	1.0742	73	1.0604	98
1.0324	23	1.0607	49	1.0744	74	1.0580	99
1.0337	24	1.0615	50	1.0746	75	1.0553	100
1.0350	25						

SPECIFIC GRAVITY AND PERCENTAGE OF ALCOHOL BY VOLUME

(Squibb)

Per Cent Alcohol by Volume	Specific Gravity at $\frac{15.56^\circ}{15.56^\circ}$ C.	Per Cent Alcohol by Volume	Specific Gravity at $\frac{15.56^\circ}{15.56^\circ}$ C.	Per Cent Alcohol by Volume	Specific Gravity at $\frac{15.56^\circ}{15.56^\circ}$ C.	Per Cent Alcohol by Volume	Specific Gravity at $\frac{15.56^\circ}{15.56^\circ}$ C.
1	0.9985	26	0.9698	51	0.9323	76	0.8745
2	.9970	27	.9691	52	.9303	77	.8721
3	.9956	28	.9678	53	.9283	78	.8696
4	.9942	29	.9665	54	.9262	79	.8664
5	.9930	30	.9652	55	.9242	80	.8639
6	.9914	31	.9643	56	.9221	81	.8611
7	.9898	32	.9631	57	.9200	82	.8581
8	.9890	33	.9618	58	.9178	83	.8557
9	.9878	34	.9609	59	.9160	84	.8526
10	.9869	35	.9593	60	.9135	85	.8496
11	.9855	36	.9578	61	.9113	86	.8466
12	.9841	37	.9565	62	.9090	87	.8434
13	.9828	38	.9550	63	.9069	88	.8408
14	.9821	39	.9535	64	.9047	89	.8373
15	.9815	40	.9519	65	.9025	90	.8340
16	.9802	41	.9503	66	.9001	91	.8305
17	.9789	42	.9490	67	.8973	92	.8272
18	.9778	43	.9470	68	.8949	93	.8237
19	.9766	44	.9452	69	.8925	94	.8199
20	.9760	45	.9434	70	.8900	95	.8164
21	.9753	46	.9416	71	.8875	96	.8125
22	.9741	47	.9396	72	.8850	97	.8084
23	.9728	48	.9381	73	.8825	98	.8041
24	.9716	49	.9362	74	.8799	99	.7995
25	.9709	50	.9343	75	.8769	100	.7946

The tables giving the percentage of alcohol by weight and by volume do not agree with each other. The density of absolute alcohol given by Fownes is .7938 at 15.6° C. (60° F.) compared with water at the same temperature. Under the same conditions Tralles finds a density of .7946. Squibb has shown that the density of absolute alcohol must be at least as low as .7935. This is .003 lower than the density found by Fownes and corresponds to 0.1 per cent of alcohol. The table given by Squibb is based on the values given by Fownes for percentage by weight and those given by Tralles for percentage by volume.

To reduce sp. gr. at $\frac{15.6^\circ}{15.6^\circ}$ to $\frac{15.6^\circ}{4^\circ}$ multiply by .99908 or for

sp. gr. 1.000 to .935 subtract .0009
" .934 to .825 " .0008
" .824 " .0007

DENSITIES OF METALS

The values given are in gms. per cc. at the ordinary room temperature unless otherwise stated.

Density × 62.335 = lbs. per cu. ft.

Aluminum	2.70
Commercial wrought, 2.67; cast	2.56
Wire (free from SiO_2)	2.70
Pure	2.58
Liquid at M. P. (720° C.)	2.43
Antimony	6.62
Distilled in vacuo	6.62
Distilled in vacuo and compressed	6.69
Amorphous	6.22
Liquid at M. P. (620° C.)	6.41
Arsenic	5.72
Crystalline, gray, 5.72; black	4.64
Amorphous, brown	3.70
Bismuth	9.80
Distilled in vacuo	9.78
Electrolytic	9.75
Wire	9.85
Solid at M. P. (271° C.)	9.67
Liquid	10.00
Cadmium	8.64
Rolled	8.66
Distilled in vacuo	8.65
Wire, cold drawn	8.64
Solid at M. P. (318° C.)	8.37
Liquid at M. P. (318° C.)	7.99
Copper	8.93
Cast	8.30–8.92
Wire	8.93–8.95
Beaten	8.92–8.96
Electrolytic	8.88–8.95
Distilled in vacuo	8.93
Gold	19.3
Cast	19.29
Rolled	19.31
Wire: soft drawn, 19:26; hard drawn	19.25
Crystalline from solution	19.43
Iron	7.86
Pure	7.85–7.88
Wrought	7.79–7.85
Cast: gray, 7.03–7.13; white	7.58–7.73
Piano wire, 7.78; annealed	7.80
Lead	11.34
Cast	11.34
Rolled	11.35
Wire	11.34
Distilled in vacuo	11.34
Solid at M. P. (325° C.)	11.01
Liquid at M.P. (325° C.)	10.65
Nickel	8.8
Cast	8.90
Malleable, sheets, etc.	8.84
Wire, cold drawn	8.76
Wire, cold drawn, annealed	8.84
Platinum	21.4
Pure, cast and beaten	21.4
Wire, cold drawn	21.4
Platinum sponge	21.1
Silver	10.50
Cast	10.42–10.51
Commercial, pure	10.36
Electrolytic	10.53
Tin	7.28
Commercial Tin (white Tetragonal).	
Cast	7.28–7.30
Solid at M. P. (226° C.)	7.18
Liquid at M. P. (226° C.)	6.99
Rhomic modification	6.56
Gray modification	5.75–5.85
Zinc	7.1
Cast, cooled slowly	7.10–7.16
Cast, cooled quickly	7.04–7.14
Rolled	7.19
Distilled in vacuo	6.92
Distilled in vacuo and compressed	7.13

DENSITIES OF ALLOYS

The values given below are in gms. per cc. at ordinary temperatures. Compositions are percentage by weight.

Brass, Yellow, 70 Cu + 30 Zn, cast	8.44
" " " " rolled	8.56
" " " " drawn	8.70
" Red, 90 Cu + 10 Zn	8.60
" White, 50 Cu + 50 Zn	8.20
Bronze, 90 Cu + 10 Sn	8.78
" 85 Cu + 15 Sn	8.89
" 80 Cu + 20 Sn	8.74
" 75 Cu + 25 Sn	8.83
German Silver, 26.3 Cu + 36.6 Zn + 36.8 Ni	8.30
" " 52 Cu + 26 Zn + 22 Ni	8.45
" " 59 Cu + 30 Zn + 11 Ni	8.34
" " 63 Cu + 30 Zn + 6 Ni	8.30
Monel Metal	8.80
Copper and Aluminum, 97 Cu + 3 Al	8.69
" " 95 Cu + 5 Al	8.37
" " 90 Cu + 10 Al	7.69
Aluminum and Zinc, 91 Al + 9 Zn	2.80
Wood's Metal, 50 Bi + 25 Pb + 12.5 Cd + 12.5 Sn	9.70
Bismuth, Lead and Tin, 53 Bi + 40 Pb + 7 Sn	10.56
Antimony and Bismuth, 54 Sb + 46 Bi	7.86
Antimony and Tin, 51.4 Sb + 48.6 Sn	11.46
" " 9.5 Sb + 90.5 Sn	9.36
Iron and Silicon (Durion), 84.5 Fe + 14 Si + 1.5 other Elements	7.00
Iron and Antimony, 55 Fe + 45 Sb	8.16
Tin and Cadmium, 68 Sn + 32 Cd	7.70
Lead and Tin, 87.5 Pb + 12.5 Sn	10.60
" " 84 Pb + 16 Sn	10.33
" " 77.8 Pb + 22.2 Sn	10.05
" " 63.7 Pb + 36.3 Sn	9.43
" " 46.7 Pb + 53.3 Sn	8.73
" " 30.5 Pb + 69.5 Sn	8.24
Lead and Mercury, 51 Pb + 49 Hg	12.48
Mercury and Tin, 77.5 Hg + 22.5 Sn	11.46
" " 46.3 Hg + 53.7 Sn	9.36
Silver and Lead, 51 Ag + 49 Pb	10.92
" " 2 Ag + 98 Pb	11.33
Silver and Copper, 94.4 Ag + 5.6 Cu	10.36
" " 89.3 Ag + 10.7 Cu	10.39
" " 66.3 Ag + 33.7 Cu	10.09
" " 49.65 Ag + 50.35 Cu	9.65
" " 29.5 Ag + 70.5 Cu	9.32
Gold and Silver, 78.5 Au + 21.5 Ag	16.35
" " 64.6 Au × 35.4 Ag	14.87
" " 47.7 Au + 52.3 Ag	13.43
" " 23.5 Au + 76.5 Ag	11.76
Gold and Copper, 98 Au + 2 Cu	18.84
" " 96 Au + 4 Cu	18.36
" " 94 Au + 6 Cu	17.95
" " 92 Au + 8 Cu	17.52
Gold and Lead, 8.7 Au + 91.3 Pb	11.84
Platinum and Iridium, 90 Pt + 10 Ir	21.62
" " 85 Pt + 15 Ir	21.62
" " 66.7 Pt + 33.3 Ir	21.87
" " 5 Pt + 95 Ir	22.38

DENSITIES OF VARIOUS SUBSTANCES

The values given below are approximate densities in gms. per cc. at ordinary room temperature.

Density × 62.335 = lbs. per cu. ft.

Asbestos	2.1–2.8
Asbestos board	1.2
Basalt	2.7–3.2
Bone	1.7–2.0
Brickwork	1.5–1.7
Celluloid	1.4
Cement	2.7–3.0
Charcoal (wood)	0.3–0.6
Coke (absolute density)	1.4
Coke (apparent)	0.5
Cork	0.2
Cotton (air dried)	1.5
Ebonite	1.2
Fire Brick	1.8–2.2
Flax (air dried)	1.5
Gas Carbon	1.8–2.0
Gelatine	1.3
Glass, Bottle	2.6–2.7
Crown ordinary	2.4
Crystal ordinary	3.3
Flint	2.9–3.4
Plate	2.5
Window	2.5
Glue	1.3
Granite	2.5–3.0
Gum arabic	1.3–1.4
Gutta Percha	1.0
India Rubber, raw	0.9–1.0
India Rubber, vulcanized	1.2–1.7
Ivory	1.8–1.9

Leather	0.9–.01
Loam	1.5–2.3
Marble	2.5–2.8
Marl	2.3–2.5
Masonry	2.4
Methylated Spirit	0.8
Milk	1.03
Mortar (lime) apparent	1.8
Paper	0.7–1.1
Paraffin Wax	0.8–0.9
Pitch	1.1
Porcelain	2.2–2.5
Pumice, natural	0.4–0.9
Resin (pine)	1.1
Sand-dry absolute	1.5
Sand-dry apparent	2.6
Sandstone	2.2–2.5
Sandstone, artificial	2.0
Sea-water	1.03
Silica fused transparent	2.2
Silica fused translucent	2.1
Silk, natural	1.6
Slag	2.5–3.0
Slaked lime, apparent	1.3–1.4
Slate	2.6–2.7
Steel	7.8–7.9
Tile	1.8
Turpentine	0.9
Vinegar	1.1
Wool (air dried)	1.3

Seasoned woods:

Alder	0.5
Ash	0.7–0.8
Bamboo	0.4
Beech	0.7
Birch	0.7
Cedar	0.5–0.7
Cypress	0.5
Ebony	1.2
Elm	0.6–0.7
Larch	0.5

Lignum-vitæ	1.2–1.4
Mahogany	0.6–0.8
Maple	0.7
Oak	0.7–1.0
Pine (white)	0.5–0.6
Pine (yellow)	0.5–0.8
Poplar	0.4–0.5
Teak	0.8–0.9
Walnut	0.7
Willow	0.5–0.6

DIAMETER IN FEET AND INCHES, AREA IN SQUARE FEET AND U. S. GALLONS CAPACITY FOR ONE FOOT IN DEPTH OF CYLINDRICAL TANKS

$$1 \text{ gallon} - 231 \text{ cubic inches} = \frac{1 \text{ cubic foot}}{7.4805} = 0.13368 \text{ cubic feet}$$

Diam.		Area	Gals.	Diam.		Area	Gals.
Ft.	In.	Sq. Ft.	1 Foot Depth	Ft.	In.	Sq. Ft.	1 Foot Depth
1		0.785	5.87	4	10	18.35	137.25
1	1	0.922	6.89	4	11	18.99	142.02
1	2	1.069	8.00	5		19.63	146.88
1	3	1.227	9.18	5	1	20.29	151.82
1	4	1.396	10 44	5	2	20.97	156.83
1	5	1.576	11.79	5	3	21.65	161.93
1	6	1.767	13.22	5	4	22.34	167.12
1	7	1.969	14.73	5	5	23.04	172.38
1	8	2.182	16.32	5	6	23.76	177.72
1	9	2.405	17.99	5	7	24.48	183.15
1	10	2.640	19.75	5	8	25.22	188.66
1	11	2.885	21.58	5	9	25.97	194.25
2		3.142	23.50	5	10	26.73	199 92
2	1	3.409	25.50	5	11	27.49	205.67
2	2	3.687	27.58	6		28.27	211.51
2	3	3.976	29.74	6	3	30.68	229.50
2	4	4.276	31.99	6	6	33.18	248.23
2	5	4.587	24.31	6	9	35.78	267.69
2	6	4.909	36.72	7		38.48	287.88
2	7	5.241	39.21	7	3	41.28	308.81
2	8	5.585	41.78	7	6	44.18	330.48
2	9	5.940	44.43	7	9	47.17	352.88
2	10	6.305	47.16	8		50.27	376.01
2	11	6.681	49.98	8	3	53.46	399.88
3		7.069	52.88	8	6	56.75	424.48
3	1	7.467	55.86	8	9	60.13	449.82
3	2	7.876	58.92	9		63.62	475.89
3	3	8.296	62.06	9	3	67.20	502.70
3	4	8.727	65.28	9	6	70.88	530.24
3	5	9.168	68.58	9	9	74.66	558.51
3	6	9.621	71.97	10		78.54	587.52
3	7	10.085	75.44	10	3	82.52	617.26
3	8	10.559	78.99	10	6	86.59	647.74
3	9	11.045	82.62	10	9	90.76	678.95
3	10	11.541	86.33	11		95.03	710.90
3	11	12.048	90.13	11	3	99.40	743.58
4		12.566	94.00	11	6	103.87	776.99
4	1	13.095	97.96	11	9	108.43	811.14
4	2	13.635	102.00	12		113.10	846.03
4	3	14.186	106.12	12	3	117.86	881.65
4	4	14.748	110.32	12	6	122.72	918.00
4	5	15.321	114.61	12	9	127.68	955.09
4	6	15.90	118.97	13		132.73	992.91
4	7	16.50	123.42	13	3	137.89	1031.5
4	8	17.10	127.95	13	6	143.14	1070.8
4	9	17.72	132.56	13	9	148.49	1110.8

DIAMETER IN FEET AND INCHES, ETC. (Continued)

Diam.		Area	Gals.	Diam.		Area	Gals.
Ft.	In.	Sq. Ft.	1 Foot Depth	Ft.	In.	Sq. Ft.	1 Foot Depth
14		153.94	1151.5	23	6	433.74	3244.6
14	3	159.48	1193.0	23	9	443.01	3314.0
14	6	165.13	1235.3	24		452.39	3384.1
14	9	170.87	1278.2	24	3	461.86	3455.0
15		176.71	1321.9	24	6	471.44	3526.6
15	3	182.65	1366.5	24	9	481.11	3598.9
15	6	188.69	1411.5	25		490.87	3672.0
15	9	194.83	1457.4	25	3	500.74	3745.8
16		201.06	1504.1	25	6	510.71	3820.3
16	3	207.39	1551.4	25	9	520.77	3895.6
16	6	213.82	1599.5	26		530.93	3971.6
16	9	220.35	1648.4	26	3	541.19	4048.4
17		226.98	1697.9	26	6	551.55	4125.9
17	3	233.71	1748.2	26	9	562.00	4204.1
17	6	240.55	1799.3	27		572.56	4283.0
17	9	247.45	1851.1	27	3	583.21	4362.7
18		254.47	1903.6	27	6	593.96	4443.1
18	3	261.59	1956.8	27	9	604.81	4524.3
18	6	268.80	2010.8	28		615.75	4606.2
18	9	276.12	2065.5	28	3	626.80	4688.8
19		283.55	2120.9	28	6	637.94	4772.1
19	3	291.04	2177.1	28	9	649.18	4856.2
19	6	298.65	2234.0	29		660.52	4941.0
19	9	306.35	2291.7	29	3	671.96	5026.6
20		314.16	2350.1	29	6	683.49	5112.9
20	3	322.06	2409.2	29	9	695.13	5199.9
20	6	330.06	2469.1	30		706.86	5287.7
20	9	338.16	2529.6	30	3	718.69	5376.2
21		346.36	2591.0	30	6	730.62	5465.7
21	3	354.66	2653.0	30	9	742.64	5555.4
21	6	363.05	2715.8	31		754.77	5646.1
21	9	371.54	2779.3	31	3	766.99	5737.5
22		380.13	2843.6	31	6	779.31	5829.7
22	3	297.61	2908.6	31	9	791.73	5922.6
22	6	397.61	2974.3	32		804.25	6016.2
22	9	406.49	3040.8	32	3	816.86	6110.6
23		415.48	3108.0	32	6	829.58	6205.7
23	3	424.56	3175.9	32	9	842.39	6301.5

From Kent's "Mechanical Engineers' Pocketbook"

PHYSICAL PROPERTIES OF ACID-RESISTING BRONZES

Grade of Bronze	Form	Tensile Strength per Sq. Inch in Pounds	Yield Point per Sq. Inch in Pounds	Elongation in 2 Inches %	Reduction of Area %
•HY-TEN-SL Bronze...	Castings	105,000	60,000	15.0	15.0
HY-TEN-SL Bronze...	Rolled	110,000	70,000	12.0	20.0
Manganese SMB......	Castings	70,000	35,000	30.0	30.0
Manganese AMB......	Castings	62,000	30,000	25.0	25.0
Naval................	Rolled and Forged	54,000	25,000	40.0	45.0
Phosphor No. 1.......	Castings	25,000	18,000	4.0	30.0
U. S. Gov't Gun......	Castings	40,000	20,000	20.0	20.0

COMPARISON OF PHYSICAL PROPERTIES OF ALUMINUM, BRASS AND STEEL

Property	Aluminum	Brass	Steel
Melting Point, ° C..............	658	950	1482
Melting Point, ° F..............	1217	1740	2700
Annealing Point, ° C............	427 to 482	500	600–650
Annealing Point, ° F............	800 to 900	868	1110–1200
Specific Heat (Water :: 1).......	0.2185	0.094	0.1165
Thermal Conductivity (Silver :: 100)........................	51.	23.8	11.
Coefficient Linear Expansion, per ° C........................	0.0000222	0.0000189	.00001144
Coefficient Linear Expansion, per ° F........................	0.0000123	0.0000105	.00000636
Specific Gravity, Cast...........	2.56	8.10	7.70
Specific Gravity, Rolled.........	2.71	8.51	7.90
Weight in lbs. per cu. in., cast...	0.0924	0.294	....
Weight in lbs. per cu. in., rolled...	0.0978	0.308	0.2839
Tensile Strength, lbs. per sq. in., cast........................	12,000	18,000	55,000
Tensile Strength, lbs. per sq. in., rolled.......................	12,500 to 29,000	22,400	65,000
Modulus of Elasticity in lbs. per sq. in.......................	9,000,000	9,200,000	30,000,000

SHEET, ALUMINUM, COPPER, BRASS, ZINC, STEEL

Weights per Square Foot

Water at 15° C ....62.3737 pounds per cubic foot

	Aluminum	Copper	Brass	Zinc	Steel
Specific Gravity Rolled Metal...	2.71	8.890	8.512	7.191	7.858
Pound per cubic inch	.0978	.3212	.3075	.2598	.2839

Thickness, Inches	Aluminum, Lbs.	Copper, Lbs.	Brass, Lbs.	Zinc, Lbs.	Steel, Lbs.
.1250	1.7607			4.6760	5.1096
.1144	1.6117	5.2906	5.0656		
.1090	1.5353				4.4557
.1019	1.4353	4.7125	4.5121		
.1000	1.4086			3.7408	
.0938	1.3212				3.8344
.0907	1.2781	4.1946	4.0162		
.0900	1.2677			3.3667	
.0808	1.1382	3.7367	3.5778		
.0800	1.1268			2.9927	
.0781	1.1001				3.1926
.0720	1.0136	3.3297	3.1882		
.0703	.9902				2.8737
.0700	.9860			2.6186	
.0641	.9026	2.9644	2.8383		
.0625	.8803				2.5549
.0600	.8451			2.2445	
.0571	.8038	2.6407	2.5284		
.0563	.7930				2.3014
.0550	.7747			2.0575	
.0508	.7158	2.3493	2.2494		
.0500	.7043			1.8704	2.044
.0453	.6375	2.0950	2.0059		
.0450	.6338			1.6834	
.0438	.6169				1.7905
.0403	.5676	1.8637	1.7845		
.0400	.5634			1.4963	
.0375	.5282				1.5329
.0360	.5071			1.3467	
.0359	.5055	1.6602	1.5897		
.0344	.4845				1.4062
.0320	.4501	1.4799	1.4169	1.1971	
.0313	.4408				1.2795

MECHANICAL PROPERTIES OF SHEET ALUMINUM (PURE AND ALLOYED)

Kind of Metal	Tensile Strength Lb. /Sq. In.	Yield Point Lb./Sq. In.	Elongation in 2 inches in per cent	Brinnell Hardness
2SO	12,000	3,000 to 5,000	25 to 35	22 to 26
2SH	20,000	14,000 to 22,000	3 to 1	45 to 55
3SO	18,000	7,000 to 8,000	15 to 25	32 to 36
3SH	30,000	16,000 to 24,000	4 to 1	55 to 65
17SO	26,000	7,000 to 10,000	18 to 12	47 to 55
17SH	40,000 to 45,000	35,000 to 40,000	4 to 2	65 to 80
17ST	50,000 to 55,000	30,000 to 35,000	20 to 18	85 to 105
17SRT	60,000 to 75,000	45,000 to 60,000	10 to 1	105 to 160

MECHANICAL PROPERTIES OF MONEL METAL

Material	Tensile Properties			
	Proportional Limit psi	Yield Point psi	Tensile Strength psi	Elongation in 2 in. %
Hot rolled rods and rounds up to 1″ diam	+39,700	51,300	91,500	46
$1\frac{1}{16}$″–$1\frac{11}{16}$″ diam	+47,700	59,600	93,200	37
$1\frac{3}{4}$″–$2\frac{7}{16}$″ diam	+40,200	51,900	90,300	42
$2\frac{1}{2}$″–$3\frac{1}{2}$″ diam	+32,200	41,800	88,900	46
Over $3\frac{1}{2}$″	+37,200	50,300	88,400	43
Hexagonals	49,100	60,600	92,300	38
Rectangles	35,800	47,000	89,800	47
Castings	.....	30,000 to 40,000	65,000 to 80,000	25 to 35
Sheet (soft)	.....	25,000 to 35,000	65,000 to 75,000	35 to 45
Wire (hard)	....	100,000 to 130,000	110,000 to 140,000	1 to 2
Wire (soft)	.....	25,000 to 30,000	65,000 to 75,000	20 to 30
Cold Drawn Rods	.....	60,000 to 90,000	80,000 to 100,000	20 to 30

+Tensile properties and hardness are average for 1919–1920.

Material	* Torsional Properties				Hardness		
	Proportional Limit	Yield Point	Ultim. Str.	Shearing Deformation in ins. per in. of gage lgth.	B. H. N. 3,000	B. H. N. 500	Scleroscope Universal Hammer
Hot rolled rods and rounds up to 1″ diam.	25,200	30,000	62,000	2.78	144	113	22
1 1/16″–1 11/16″ diam.	29,700	38,600	61,800	2.83	162	130	23
1 3/4″–2 7/16″ diam.					161	127	23
2 1/2″–3 1/2″ diam.	20,200	26,700	63,300	2.64	147	120	23
Over 3 1/2″	24,200	32,200	62,100	2.57	152	120	24
Hexagonals	......	......	......	......	167	133	25
Rectangles	......	......	......	......	144	114	24
Castings	......	......	......	......	105 to 115	......	......
Sheet (soft)	......	......	......	......	......	100 to 120	......
Wire (hard)	......	......	......	......	......	......	......
Wire (soft)	......	......	......	......	......	......	......
Cold Drawn Rods	......	......	......	......	180 to 200	......	......

*Torsional properties, average of 72 tests.

PHYSICAL PROPERTIES OF MONEL METAL

Color—white.
Density (specific gravity) .... 8.80 g/cc.
Weight per cu. in .... .318 lbs.
Melting point .... 1300–1350° C. (2370–2460° F.)
Shrinkage (pattern) .... 1/4″ per foot

Coefficient of thermal expansion	25–100° C.	0.000014 per ° C.
	25–300° C.	0.000015 per ° C.
	25–600° C.	0.000016 per ° C.

Electrical resistivity 256 ohm-mil-foot (42.5 microhm-cm.) (conductivity 4% of that of copper).
Coefficient of electrical resistivity—.0019 per ° C. or .0011 per ° F.
Optical reflection coefficient—60%.
Thermal conductivity—.06 cgs units (conductivity 1/16 that of copper).
Specific heat (20–1,300 C.)—.127 cal./g.

Magnetic induction at 100 gausses	Cast Metal	500 Gausses
	Rolled Metal	1,0000–1,5000 "

Young's Modulus of Elasticity—25,000,000 psi.
Torsional Modulus—9,500,000 psi.
Compression tests of hot rolled Monel rods—
  Proportional limit .... 35,000—45,000 psi
  Yield point .... 60,000—70,000 psi
Resistance to alternating stress in rotating beam machine—approx. 100,000,000 alternations at proportional limit; i.e., the endurance safe limit.
Izod test—100 ft. lbs. on standard specimen.

PHYSICAL AND MECHANICAL PROPERTIES OF DURIRON

Specific gravity	7.00
Weight per cu. in.	0.253 lb.
Tensile strength	about 10,000 lbs. per sq. in.
Transverse strength	1,000 lbs. with deflection between $\frac{1}{16}''$ and $\frac{1}{8}''$
Compression strength	70,000 lbs. per sq. in.
Melting point	about 2300° F.
Coefficient of expansion	.00001565 per degree F.
Shore scleroscope hardness	49–51
Contraction allowance in casting	$\frac{3}{16}''$ per foot
Electrical resistivity	63.3 Microhms per c.c. at 0° C.
	71.2 Microhms per c.c. at 18° C.
	94.4 Microhms per c.c. at 100° C.

THERMAL CONDUCTIVITY (VALUES, EXCEPT DURIRON FROM KENT)

Silver	Copper	Aluminum	Cast Iron	Duriron	Lead	Glass
1000	811	665	359	323	287	2

COMPOSITION AND PROPERTIES OF ELECTRICAL ALLOYS*

Name of Alloy	Form in Which Produced	Chemical Composition					Resistivity in Microhm, Cm.	Electrical Resistivity		Tensile Strength, Lb. per Sq. In.	Density	Melting Point or Range Deg. C.	Recommended Max. Working Temp. Deg. C.	Thermal Expansivity, Deg. C.
		Ni	Cr	Cu	Fe	Mn		Temperature Coefficient, per Deg. C.	Resistivity in Ohm, Mil-Ft. at 75 Deg. F.					
A—Nickel:Chromium Alloys														
Nichrome (*a*)	Wire, ribbon	60	12		26	2	109.5	0.00017	660	100,000	8.15		1,000	0.000164
Nichrome (*a*)	Castings (*f*)									50,000 to 55,000	8.15		1,100	0.000121
Nichrome 2 (*a*)	Wire, ribbon	66	22		10	2	110 to 113	0.00017	660 to 680		8.02		1,100	
Kromore (*a*)	Wire, ribbon	85	15				96.4–101.5	0.00024	580 to 610					
Chromel A (*c*)	Wire, ribbon, catgs.	80	20				103	0.00011	620		8.3		1,100	
Chromel B (*c*)	Wire, ribbon	85	15				89	0.00011	535		8.46			
Chromel C (*c*)	Wire, ribbon	64	11		25		108	0.00018	650		8.16			
Calorite		65	12		15	8	110		662					
Calido (*b*)	Wire, ribbon	65	12		23		103	0.00036	620	Hard, 160,000 Soft, 80,000	8.15	1,530	1,000	0.000016
Excello		85	14		0.5	0.5	92		554					
Rayo (*b*)	Wire, ribbon	85	15				95.7	0.00018	575	Hard, 160,000 Soft, 80,000	8.05	1,530	1,100	0.000015
Tophet		61	10		26	3	107		644					
Chromel (*c*)		89	10		1									
Nichroloy 1 (*d*)		75	16		7 to 9	3								
Nichroloy 2 (*d*)		40	7		50	3								
Nichroloy (*d*)	Castings (*g*)	23	20		50	1							1,100	
Kromax		80	20											
B—Ferronickel Alloys														
Climax (*a*)	Wire, ribbon	25			75		83.1	0.00098	500		8.14			0.0000171
No. 193 (*a*)	Wire, ribbon	30	2		68		87.2	0.0007	525		8.14			0.0000171
Comet (*b*)	Wire, ribbon	32	3		bal.		87.0	0.0007	525	Hard, 150,000	8.15	1,510	600	0.000016
Phenix (*b*)	Wire, ribbon	25			bal.		83.1	0.0011	500	Soft, 70,000	8.10	1,510	600	0.000017
Ferrozoid (*e*)							84.0		506	Hard, 140,000				
Kruppin (*e*)		28			bal.		85.0		512	Soft, 70,000				
Vestalin (*e*)							85.1		512					
C—Nickel:Copper Alloys														
Advance (*a*)		44 to 46		bal.		0.75 to 1.25	48.9	nil	294		8.9			0.0000144
Ideal (*b*)	Wire, ribbon	45		55			49.2	0.000005	296	Hard, 115,000 Soft, 60,000	8.9	1,210	500	0.000014

Lucero (*b*)	Wire, ribbon	65	......	30	......	bal.	46.5	0.0007	280	Hard, 140,000 Soft, 65,000	8.9	1,350	600	0.000014
Nickelin (*e*)		31 to 32	......	55 to 68	Zn 6	to 13	43.0	....	258	....	......	......	......	....
Ferry (*e*)		......	......	......	......	......	47.2	....	284	....	......	......	......	....
Constantan		40 to 55	......	bal.	......	......	48 to 50	....	295 to 300	....	......	......	......	....
Eureka (*e*)	Similar to Constantan	......	......	......	......	......	50.2	....	302	....	......	......	......	....
Monel		67	......	28	balance		42.5	0.0019	256	....	......	......	......	....
D—Nickel:Silver Alloys														
18% (*a*)		......	......	......	......	......	36.3	0.00030	218	....	8.5	......	......	....
7% (*e*)		......	......	......	......	......	18.0	....	108	....	......	......	......	....
10% (*e*)		......	......	......	......	......	21.0	....	126	....	......	......	......	....
20% (*e*)		......	......	......	......	......	29.0	....	174	....	......	......	......	....
30% (*e*)		......	......	......	......	......	40.2	....	241	....	......	......	......	....
Platinoid		......	......	......	......	......	41.0	....	246	....	......	......	......	....
Rheotan II		25	......	52.5	5	18 Zn	......	....	....	....	......	......	......	....
E—Miscellaneous Alloys														
Alomel		94 Si_1	Al_2	......	0.5	2.5	......	....	....	....	......	......	......	....
Manganin		2 to 16	......	50 to 85	...	12 to 30	42 to 48	0.00001	250 to 290	....	......	......	......	....
Tarnac (*e*)	Cupro-manganese	......	......	......	......	......	41.0	....	246	....	......	......	......	....
Resistin (*e*)	Cupro-manganese	......	......	84 to 86	2	11 to 13	50.2	....	302	....	......	......	......	....
Magno (*b*)	Wire, ribbon	95	......	......	......	5	86.4	....	520	Hard, 140,000 Soft, 65,000	......	 1,400	800	.... 0.000014

(*a*) Data from Driver-Harris Co. (*b*) Data from Electrical Alloys Co. (*c*) Data from Hoskins Manufacturing Co. (*d*) Data from Hiram Walker & Sons Co (*e*) Law "Alloys and Their Industrial Application." (*f*) Brinnell hardness 179. Specific heat, 0.111 cal., per g. at 100 deg. C. Thermal conductivity, 0.0341 cal. per sec. per cm. (*g*) Also contains 0.5 Si 0.5 Al, 1.0 C, 1.0 V.

*Merica.

MISCELLANEOUS ALLOYS CONTAINING NICKEL *

Name of Alloy	Chemical Compositions								Remarks
	Ni	Cu	Fe	Zn	Mn	Al	Pb	Sn	
Aphit	20-21	70-75		5.2-2.2					Cd 4.5-1.8.
Ajax metal	25-50	5-20	30-70						Bearing metal, gun mountings.
Aluminum—nickel	76.4					23.6		20	Ag 10.
Aluminum—silver	20	57	20			3			
Aluminum—wire (B)	1.3	1				97.7			
Argozie	14	54		28			2	2	Castings.
Ashberry metal	1-3	2-3		1-3				78-80	Sb 14-20. Tableware.
Aterite	12-18	55-60	6-10	13-20			1-2.5		Valves and valve parts.
Bario metal	90					W1.22	Si 0.2	9 Cr	4.25 Heat and acid-resisting alloy.
Bearing metal	10.4							83.3	W 6.3. For high speeds.
Bismuth brass	31	47		21			1		Bi .1.
Bismuth bronze	24	25							Sb 50, Bi 1.
Bismuth bronze	10	53		20		1		15	Bi 1.
Bismuth bronze	32.5	45		21.5				16	Bi 1.
Chromax bronze	15.2	66.7		12.1		3.0			Cr 3.0. Can be rolled. T.S. 79,000 lbs. per sq. in. 3% elongation.
Cooperite	80								W 14, Zr 6. Cutting tools.
Cuniloy	65	25			3½		1		Resistance to corrosion and alkalis.
Cufenium	22	72	6						Knives, forks, spoons.
English nickel (complex)	2	2			1			87	Bi 0.5 W 1.5, Sb 6.
Illium	60.6	6.4							Mo 4.6, Cr 21, Acid resistance.
Invar	37		63						37% nickel steel.
Machine bronze	25	50-90		0.30			0-8	0-30	
Machine bronze	25	50						25	
Manganin	8-10	80			10-12				See p. 651.
Minargent	39.77	56.82				0.57			W 2.84.
Minargent	32	46					22		
Mira metal	0.24	74.7	0.43	0.62			16.3	0.91	Sb 6.8. For cocks, pipes, etc., to resist acid corrosion.
Neogen	12	58		27		0.5		2	
Nickel aluminum bronze	10	88				2			
Nickel aluminum bronze	40	10				30		20	
Nickel bronze	30	86						11	
Nickel bronze	20	60		12				8	
Nickel bronze	25	50						25	

Nickeloy	1.41	4.15				93 8			Cast gives 20,000 lbs./sq. in. tensile strength, 4.5% elongation.
Nickel manganese bronze	2.5	53.4		39	1.7	0.2	0.3	2 6	
Nickel-tungsten	25–50								W 50–75. Alloy for mixing.
Nickel-zirconium	86.4					6			Si 6, Zr 1.5, C 0.1. High speed cutting tools.
Plastic bronze	1	64					30	5	
Platinite	46		54						46% nickel.
Platinum substitute	72					23.6			Bi 3.7, Ar 0.7.
Platnam	58 8	32 55	0.48			0 32	12 72		Used for valve seating.
Rosein	40					30		20	Ag 10. Used for jewellers' work.
Sea water bronze	32.5	45		5 5				16	Bi 1. Resistant to sea water.
Sheathing bronze	32 5	45		5 5				16	Bi 1.5.
Sidiraphite	23	5	65						W 4, Sb 3.
Speculum	4	64						32	For telescope mirrors. Does not always contain nickel.
Stanniol	0.3	1	0.1				2 4	96 2	
Stellite	1		2						Co 75, Cr 16.5, Si 3–4, C 2. Pocket and table knives, surgical instruments, machine tools.
Stuffing box alloy	15 5	61 5		11			10	2	For turbines.
Toncas metal	28.6	35	7	7			7	7	Sb 7. Ornamental work.
Trabuk	5 5							87.5	Sb 5, Bi 2. Substitute for nickel silver; resistant to vegetable acids.
Tungsten brass									See wolfram brass.
Turbadium bronze	2	48		46					
Turbiston bronze	2	55	0.84	41	0 16	1			Resistant to salt water.
Typewriter metal	20	57		20		3			Used for typewriter parts.
Unmagnetizable watch wheels	18	18							Pt 62.75, Cd 1.25. Used for watch wheels.
Warnes metal	26							37	Bi 26, Co 11.
White gold	59								Au 41. Substitute for platinum.
White gold	15								Au 80. Substitute for platinum.
White solder	10	45		45					Soldering.
Wolfram brass	14	60		42					W 4.
Zamium	60	bal. Cr	Mn, W.						A nickel-chromium alloy, resistant to corrosion.

*Merica.

COMPOSITION OF VARIOUS GRADES OF COMMERCIAL NICKEL*

Name	Source	Form	Cu	Ni and Co	Co	Fe	S	Si	C	Mn	As	Sn and Sb	Insol.	Remarks
Nickel rod	H. Boker & Co.	Rods	0.18	97.58		0.38	0.012	0.13	0.19	1.60				
Malleable nickel A	International Nickel Co.	Rods		99.00		0.55	0.025	0.10	0.15	0.15				Typical analyses Orford Works
Malleable nickel B	Int'l Nickel Co.	Rods		98.75		0.50	0.025	0.20	0.15	1.75				Typical analyses Orford Works
Malleable nickel C	Int'l Nickel Co.	Rods		96.75		0.75	0.03	0.20	0.15	1.75				Typical analyses Orford Works
Nickel castings	Int'l Nickel Co.	Castings		98.95		0.50	0.035		0.16					Typical analyses Orford Works
Nickel sheet	Fleitmann Witte & Co.	Sheet	0.12	99.37					0.019					
Malleable nickel	Krupp (Germany)	Sheet No. 1	0.12	99.26		0.40	0.024	0.17	0.045	trace				
Rolled nickel sheet	Boker and Co.	0.0001 x 12 in.	0.12	97.99	0.88	0.49				1.32				
French 25 centimes	France	Coin	0.083	99.26	1.36	4.05	0.05	0.07	0.042	trace	0.018	0.021		
20 centisimi piece	Italy	Coin	0.089	99.23		0.31				0.17				
Arthur Krupp	Berndorf Austria	Wire rod	0.10	99.20	0.54	0.40	0.01	0.02	0.07	0.22				
Nickel rod	England	¼ in. wire	0.23	99.13	0.62	0.30	0.022	0.06	0.16	0.66				
Electro malleable nickel	Driver-Harris	0.081 in. wire		98.47		0.80	0.06	0.16	0.13	0.30				
Maleable nickel	Fleitmann Witte & Co.	Wire		98.60	trace	1.22				0.16				Royal Ontario Nickel Com's'n
Metallic nickel	U. S. Nickel Co.	Various	0.05	99.02	0.12	0.21	0.025	0.21	0.39		trace			
Pure nickel	Kalmus & Harper			99.29	nil	0.48	0.025	0.042	nil					Royal Ontario Nickel Com's'n
Nickel	New Caledonia		0.50	98.00		1.60		0.13						Royal Ontario Nickel Com's'n
Nickel	Basse & Selve		0.10	97.87	1.45	0.45	0.05	0.19	trace					Royal Ontario Nickel Com's'n
Nickel	Deloro Mining		0.05	98.00	1.60	0.75								Royal Ontario Nickel Com's'n
Norway nickel	V. Hybinette	Electro	0.06	99.52	0.89	0.36								
Orford nickel	Interntl. Nickel Co.	Electro	0.01	99.84			0.005		0.005		0.01	0.01	0.003	Analyzed by Orford (1908)
Electrolytic nickel	Hybinette process	Electro	0.10	98.75		0.50	0.01							Royal Ontario Nickel Com's'n
Nickle shot	U. S. Nickel Co.	Shot	0.06	98.98	1.01	0.58	0.006	0.19	0.16		trace	0.003		
Mond nickel	L, Mond (England)	Shot	0.03	99.36	0.06	0.39	0.002	0.11	0.11	0.09				
Mond nickel	Mond Nickel Co.	Shot	None	99.80	None		0.006	None	0.05					Analyzed by Hadfield (1899)
Nickel shot	Intern'l Nickel Co.	A shot	0.15	98.65	0.80	0.50	0.06	0.15	0.45		0.015	0.015		Analyzed by Orford (1914)
Nickel shot	Intern'l Nickel Bŏ.	X shot	0.15	99.05	0.80	0.47	0.04	0.10	0.18		0.015	0.015		Analyzed by Orford (1914)
Nickel cubes	U. S. Nickel Co.	Cubes	0.065	99.16		0.32			0.41					
Metallic nickel	Le Nickel	Cubes		99.41			0.015	0.04	0.176					
Grain nickel	Am. Nickel Works	Grain	0.13	99.17		0.51							1.06	
Mond nickel	Ludwick Mond	Grain	0.014	99.57		0.133	0.003		0.23		trace	trace	0.03	
Metallic nickel	Le Nickel	Grain		99.38			0.010	0.109	0.048	0.01				
French nickel	Le Nickel	Rondelle	0.112	99.01		0.43	0.024		0.037					
Nickel ingots	Intern'l Nickel Co.	Ingots	0.11	99.09	0.32	0.65	0.04	0.01	0.04		0.02	0.02		Analyzed by Le Nickel (1905)

NOTE.—The nickel values of some of the samples mentioned by the Royal Ontario Nickel Commission include nickel only, while in other cases they include nickel plus cobalt. International Nickel Co. metal contains about 0.4 per cent cobalt, which is usually included in the copper analysis.

*Merica

PHYSICAL PROPERTIES OF CRUCIBLE STEEL COMPANY'S SPECIAL CORROSION RESISTING STEEL

Physical Properties

Cast Ingots	Elastic Limit	47400
	Ultimate Strength	84480
(Before annealing	Elongation	19.5
or heat treating)	Reduction	16.6

		Yield Point lbs. per sq. in.	Ultimate Strength lbs. per sq. in.	Elongation in 2 in.	Red. of Area in 2″	Brinnell
Hammered Bars	Max.	107,270	146,870	67.5	69.3	302
(2, 3, 4, 5)	Min.	53,990	103,090	25.5	40.1	187
	Avg. (20)	70,550	118,480	43.95	55.6	226
						Shore
H. R. Sheet	600° C.	89,440 –	118,930 –	54.5 –	45.1 –	50 –
(2–6)		83,950	114,600	48.5	44	44
	950° C.	79,310 –	131,190 –	41. –	37.9 –	50
		71,430	130,720	37.	30.9	
	1200° C.	56,270 –	116,020 –	64. –	51. –	40 –
		54,890	98,250	59.5	42.7	36
H. R. Sheet	600° C.	117,350 –	127,000 –	32.5 –	39.7 –	57 –
(3–8)		111,600	126,900	22.5	36.3	55
	950° C.	99,100 –	134,600 –	34.5 –	41.9 –	47 –
		87,730	129,270	33.	40.2	45
	1200° C.	67,900 –	109,120 –	62.5 –	51.1 –	38 –
		57,900	99,400	51.5	47.	33

	Elastic Limit. lbs. per sq. in.	Yield Point. lbs. per sq. in.	Tensile Strength lbs. per sq. in.	Elongation in 2″	Red. of Area in 2″	Brinnell
1″ Sq. Rolled Bar (3–10)	90,500	99,500	134,250	29	49.2	269
Grade 3 1292° F.			71,470	20	24.7	
1472° F.			44,900	28.5	62.8	
1760° F.			21,395	37.5	82.4	

Compression and Torsion Values on 0.038″ Sheets and Bars

	Tension		Compression	Shear	Torsion	Impact	Hardness*	Ductility
	Bar	Sheet						
Elastic Limit	63660	152590	81610		52150 M. of R.			
Ultimate Strength	122560	203150	130300	82420	110560			
Elong. per cent 2″	29.3	26.7						
Elong. per cent 4″		20.9						
Reduction of area per cent	43.8							
Mod. of Elas.	27170000.				11713000			
Ft. lb. Energy						22.8		
Sclerescope							48	
Brinnell							244	
90 degrees rev. bend								3–4
Min. diam. over which can bend 180° without cracking								4

*Made on impact specimens.

This steel has been successfully used for the following: rails; valves; cooking utensils; vault plates and hinges; annealing boxes; flue dampers; rivet heating furnaces; instruments of low magnetism; corrosive organic acid containers; motor boat shafts; stainless cutlery; gun barrels; cast lead pots; cast cyanide pots; castings; rust resisting wires; electrical resistances wires; hardening trays.

PHYSICAL PROPERTIES OF PLATINUM

Specific gravity: 21.4 (Average of various determinations).
Melting-point: 1753° C. (U. S. Bureau of Standards).
Boiling-point: About 2650° C. Can be distilled in electric furnace.
Electric conductivity: 13.4 at ° C. (Silver = 100).
Tensile strength: 32,000 lbs. per sq. in. for annealed wire.
45,000 lbs. per sq. in. cast.
Hardness (Mohs' Scale): 4.3.
Specific heat: 0.032 at about 15° C., 0.046 at melting-point.
Latent heat of fusion: 27.18 (Richards).
Coefficient of linear expansion: 0.0000090 per degree C. (Less than that of any other common element.)
Ductility: The metals range in this order: W, Au, Ag, Pt, Fe, Ni, Cu, Al, Zn.
Malleability: Leaves of platinum have been obtained as thin as 0.000025 cm.
Heat conductivity: 0.19 from 10° to 97° C.
Weight in pounds of a cubic foot: 1335.4 lb.

PHYSICAL PROPERTIES OF VITREOSIL (FUSED SILICA)

Critical Temperatures.—The melting point of vitreosil is 1750° C., its softening point 1400° C. and the devitrification point about 1100° C., the latter depending somewhat on the surrounding atmosphere.

Thermal Expansion.—One of the most valuable of the many unusual characteristics of vitreosil is its extremely small expansion and contraction with variations of temperature, its linear expansion of .00000054 per degree Centigrade being the smallest of any known material. The following table shows a comparison with other well-known substances:

Material	Linear expansion per degree Centigrade
Fused silica	.00000054
Nickel Steel (36% Ni)	.0000009
Glass, Jena 59	.0000057
Glass, Pyrex 702 EJ	.0000035
Berlin Porcelain	.0000028

Weight.—The specific gravity of transparent vitreosil is approximately 2.22 and of the non-transparent material about 2.07.

Electrical Characteristics.—Investigations by the Bureau of Standards and the National Physical Laboratory show the superiority of fused silica as an electrical insulator compared with glass, porcelain and similar materials, the resistance decreasing much more slowly with rise of temperature, while the higher melting point of fused silica permits its employment at temperatures where the use of glass and porcelain is out of the question. According to Bureau of Standards Scientific Paper No. 234, hard rubber, mica, porcelain and glass have much smaller volume resistivities than fused quartz, even at room temperature. The dielectric strength of vitreosil is also very high.

A LIST OF ALLOYS*

BRASSES

	Cu	Zn	Sn	Pb	Fe	Other Elements
Admiralty, A	70.	29.	1.			
Aitch Metal	60.	38.2			1.5	
Aluminum Brass	63.	33.3				Al, 3.3; Si, 0.3
Anvil Brass	62.50	37.50				
Arko	80.	20.				
Augsburg	71.9	27.6				
Austrian Journal Box	92.5	7.5				
Bath Metal	55.	45.				
BathMetal	83.	17.				
Battery Copper	94.00	6.00				
Bell Brass	64.25	35.00	0.75			
Belt Lace	62.00	38.00				
Best Bronze	90.00	10.00				
Binding Brass	63.25	35.00		1.75		
Birmingham Platina	46.6	53.15			0.25	
Bismuth Brass	47.	21.	1.			Ni, 30.9; Bi, 0.1
Blatt Gold	77.	23.				
Block Brass	66.50	32.00		1.50		
Bobierre Metal	66.	34.				
Bobierre Metal	58.2	41.7				
Bow Wire	93.00	2.00	5.00			
Brazing Metal, F	85.	15.				
Brazing Brass	75.00	25.00				
Bright Cap Gilding	89.75	9.87		0.38		
Bristol	75.7	24.3				
Bristol	67.2	32.8				
Bristol	60.8	39.2				
Bronze Powder	84.0	16.0				
Brush Wire	64.25	35.	0.75			
Buckle Brass	65.00	35.				
Bullet Brass	90.	9.		1.		
Burr Brass	62.00	38.00				
Burr Metal	90.00	10.00				
Butt Brass	65.50	33.50		1.		
Butt Brass	63.50	35.50		1.		
Button Brass	89.50	10.00	0.50			
Button Metal	43.	57.				
Button Metal, Ludensheidt	20.	80.				
Buttons (Thurston):						
Bristol Alloy	57.9	36.8	5.3			
Bristol Alloy	61.12	36.11	2.77			
Jackson's Alloy	63.88	30.55	5.55			
Jackson's Alloy	63.01	35.61	1.39			
"Bidery"	48.50	33.32	6.06	12.15		
"Gold"	58.71	33.03	5.50	2.75		
Cap Gilding	90.00	10.00				
Cartridge Brass	66.67	33.33				
Cartridge Brass	68.00	32.00				
Cartridge Brass	70.00	30.00				
Cartridge Gilding	93.00	7.00				
Chamet Bronze	62.	38.				
Check Brass	62.	38.				
Chrysokalk	90.5	7.9		1.6		
Chrysokalk	58.7	40.2		1.1		
Chrysorin	72.	28.				
Chrysorin	66.7	33.3				
Chrysorin	63.3	36.7				
Clinching Screw Wire	69.	29.50		1.50		
Clock Brass	62.50	35.75		1.75		
Collet Brass	61.00	36.50		2.50		
Commercial Bronze	90.00	10.00				
Commercial Brass, B-r	63.	37.				
Commercial Castings, B-c	62.	30.	6.	2.		
Common Brass	65.	35.				
Cuivre Poli	70.	30.				
Cymbal Metal	78.	22.				
Delatot's Metal	80.	18.				Mn, 2.0
Delta Metal	55.1	43.5		0.37	1.08	P, 0.1
Delta Krupp	55.94	41.61		0.72	0.87	Mn, 0.81; P, 0.013

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* **William Campbell in Proc. Am. Soc.** Testing Materials, 1922, with certain additions by the authors.

A LIST OF ALLOYS (Continued)

BRASSES (Continued)

	Cu	Zn	Sn	Pb	Fe	Other Elements
Delta Krupp	55.8	40.07		1.82	1.28	Mn, 0.96
Delta Krupp	55.82	41.41		0.76	0.86	Mn, 1.38
Delta Krupp	54.22	42.25		1.10	0.99	Mn, 1.09
Diaphragm Brass	95.00	2.00	3.			
Dipping Brass	66.66	33.34				
Door Plate Brass	65.	35.				
Door Plate Brass	63.	35.		2.00		
Doctor Metal	88.	9.50	2.50			
Drawing Brass, Deep	70.	30.				
Drawing Brass	66.67	33.33				
Drill Rod	62.	35.50		2.50		
Durana	65.	30.	2.		1.5	Al, 1.5
Dutch Metal	76.	24.				
Electrical Brass Castings, B. E.	84.	13.	3.			
English	70.3	29.3	0.17	0.26		
Engravers' Brass	66.	33.		1.00		
Escutcheon Pin Brass	64.50	35.07		0.43		
Eyelet Brass	68.	32.				
Eyelet Brass	65.	35.				
Fan Blades	61.50	37.00		1.50		
Flush Plate	65.75	32.75		1.50		
Fob Metal	87.50	12.00	0.50			
Forbes Metal (Button)	46.5	53.5				
Forgings	60.	40.				
Forgings	57.	43.				
Forgings, Russian	53.5	42.				Mn, 4.5
Fourdrinier Wire	84.63	15.	0.37			
Fourdrinier Wire	80.	20.				
Free Cutting Bronze	88.50	10.00		1.50		
Gedges Metal	60.	38.5			1.5	
Gold Leaf Metal	84.	16.				
God Leaf	66-80	34-20				
Gold Leaf Jemmapes	64.6	33.7	1.4	0.2		
Gold Leaf Aix	64.8	32.8	2.0	0.4		
Gong Metal	78.	22.				
Grommet Brass	70.	30.				
Guettier's Button	56.	44.				
Guettier's Button	61.5	32.	6.5			
Guettier's Button	61.4	28.9	9.7			
Hamilton Metal	66.7	33.3				
Halberland Alloy	87.	13.				
Hardware Bronze	88.	12.				
Hardware Bronze	88.	9.50	1.50	1.00		
Harlington Bronze	55.7	42.7	0.97		0.58	
Harmonia Bronze	57.	40.		0.4	1.8	
Harmonia Bronze	55.7	41.2	0.5	0.46	1.29	Al, 0.86
Helmet Bronze	70.	30.				
Helmet Metal	72.27	27.58				
Hooker Brass	61.	37.		2.00		
Iserlohn, Cast	63.7	33.5	2.5	0.3		
Jewelers Metal	91.50	6.50	2.00			
Jewelers Metal	90.	10.				
Jewelers Metal	83.	17.				
Jewelers Metal	88.	11.25	0.75			
Jewelers Metal	87.50	12.	0.50			
Jewelers Metal	91.	7.50	1.50			
Kick Plate Brass	84.	15.		1.00		
Lancashire Brass	73.	25.		2.00		
Leaded Bronze	88.50	10.00		1.50		
Low Brass	80.00	20.00				
Machinery Brass	83.	16.	1.			
Mallet Alloy	25.4	74.6				
Manganese Brass	69.5	29.5				Mn, 1.0
Manganese Brass	60.15	34.76	0.94	0.39	1.19	Mn, 2.34; Al, 0.2
Manganese Brass	55.4	39.96			1.6	Mn, 3.20; Al, 0.2
Manganese Brass	55.0	39.5			0.7	Mn, 4.3; Al, 0.5
Manganese Brass	54.2	38.2			2.4	Mn, 4.4; Ni, 0.5
Manganese Brass	85.	2.0			1.83	Mn, 10.91
Manganese Brass	80.	5.				Mn, 15
Manganese Brass	75.5	8.				Mn, 16.5
Manganese Brass	60.	15.				Mn, 25

A LIST OF ALLOYS (Continued)

BRASSES (Continued)

	Cu	Zn	Sn	Pb	Fe	Other Elements
Mn Ni Brass	65.	5.				Mn, 20.; Ni, 10.
Mn Ni Brass	59.	20.				Mn, 3; Ni, 18
Mn Ni Brass	63.5	28.28	1.22	0.17	1.44	Mn, 3.24; Ni, 2.14
Mn Ni Brass	51.15	40.			2.25	Mn, 4.15; Ni, 2.2; Al, 0.25
Mn Ni Brass	53.5	39.	.07		2.78	Mn, 1.52; Ni, 2.35
Mn-Bronze, Rolled, Mn-r	59.	30.7	1.			Mn, 0.3
Mn-Bronze, Cast, Mn-c	58.	40.				Mn, 2.
Manganin	53.4	39.	2.66			Ni, 2.5; Mn, 1.7; Al, 0.2
Manheim Gold	89.4	9.92	0.62			
Manheim Gold	83.7	9.3	7.			5 per cent of Phos. Tin
Manheim Gold	88.	12.				
Manheim Gold	80.	20.				
Market Brass	65.	35.				
Matrix Brass	62.	36.50		1.50		
Medal Metal	84.00	16.00				
Mosaic Gold	63.	35.				
Muntz Metal	60.	40.				
Naval Brass, N-c	61.	38.	1.			
Neustadt, Drawn	71.5	28.5				
Nickel Brass	54.1	43.66			0.5	Ni, 1.5
Oker, Cast	71.9	24.4		1.1	2.32	
Oker Brass (Harz)	64.24	37.27	0.59	0.12		
Optical Bronze	89.00	6.50	4.50			
Oreide	87.25	11.50	1.25			
Oreide	90.	10.				
Oreide	85.5	14.5				
Oreide	80.5	14.5	4.85	0.1		
Oreide, Brunswick	68.21	31.52	0.48			
Parson,s Mn Bronze	60.15	34.76	0.94	0.39	1.19	Mn, 2.34; Al, 0.23
Pen Metal	85.00	13.00	2.00			
Percussion Cap	95.00	5.00				
Pewter (Thurston):						
Berthier's Alloy	71.9	24.9	1.2	2.0		
Cast and worked	64.2	34.6	0.2	2.0		
Cast and worked	61.6	35.3	0.6	2.5		
Cast gilt	63.7	33.5	2.5	0.3		
Cast gilt	64.5	32.4	0.2	2.9		
For clock work	60.66	36.88	1.35	0.74		
For clock work	60.06	31.46	1.43	0.88		
Pinchbeck	93.6	6.4				
Pinchbeck	88.8	11.2				
Pinchbeck	83.33	16.76				
Pin Wire	61.00	39.00				
Platine	43.	57.				
Potinjaune	71.9	24.9	1.2	2.0		
Primer Gilding	97.00	3.00				
Prince's Metal	83.	17.				
Prince's Metal	75.	25.				
Prince's Metal	60.8	29.2				
Reed Brass	69.00	30.00	1.00			
Rich Gold Metal	90.00	10.00				
Rich Low Brass	85.00	15.00				
Rule Brass	62.50	35.00		2.50		
Rubel Metal	55.	40.				5 per cent of Al-Fe-Mn-Ni Alloy
Rubel Metal	51.	40.				5 per cent of Al-Fe-Mn-N Alloy and 4 per cent of Ferro Mn
Russian, Cast	78.	21.	1.			
Russian, Cast	70.	30.				
Russian, Cast	66.6	33.4				
Screen Plates	58.00	41.00	0.75	0.25		
Screw Bronze	93.50	5.00	1.00	0.50		
Screw Brass	78.	16.	4.5	1.5		
Screw Wire	62.00	38.00				
Seamless Tubing	60.00	40.				
Seamless Tubing	61.50	38.50				
Solder, Hard	57.	43.				
Solder, Hard	50.	50.				
Solder, White	40.	60.				

A LIST OF ALLOYS (Continued)

(BRASSES Continued)

	Cu	Zn	Sn	Pb	Fe	Other Elements
Solder (Thurston):						
Yellow, Hard	53.30	43.10	1.30	0.30		
Nearly White, Soft	44.	49.90	3.30	1.20		
White, Very Soft	57.44	27.98	14.58			
Sheet:						
Stollberg	64.8	32.8	0.4	2.0		
Jamappes	64.6	33.7	0.2	1.4		
Rosthorn-Wiln	68.1	31.9				
Oker I	69.	29.5		0.97		
Oker	55.	44.5	0.5			
Iserlohn	70.1	29.9				
Romilly	70.1	29.26	0.17	0.28		
China	56.6	38.2	3.3	1.0	1.40	
Japan	66.6	33.4				
Hegermuhl	72.16	27.45	0.2	0.79		
Hegermuhl	72.	27.	1.			
Hegermuhl	62.	37.	0.5	0.5		
Hegermuhl	62.	37.	1.			
Shell Head Brass	75.00	25.00				
Shoe Nail Brass	63.00	37.00				
Shoe Tip Metal	88.00	12.00				
Similor	89.4	9.93	0.6			
Similor	83.7	9.3	7.0			
Similor	80.	20.				
Spring Brass	72.00	28.00				
Spring Brass	66.67	33.33				
Sterro Metal	60.	38.2			1.8	
Sterro Metal	55.	42.4	0.83		1.8	
Sterro Metal	55.5	42.			2.5	
Sterro Metal	55.3	41.8			4.66	
Sterling	66.2	33.1			0.7	
Stirling, Cast	66.2	33.11		0.02	0.66	
Talmi Gold	90.	8.92				Au, 0.91
Talmi Gold	86.4	12.2	1.1		0.3	
Thurston's	55.	44.5	0.5			
Tissier's	97.	2.0	0.5			
Tissier's	97.	2.0				As, 1.0
Tobin Bronze	60.	38.	2.			
Tobin Bronze	59.	39.	2.			
Tombac:						
Oker	85.3	14.7				
Arcet	82.3	17.7				
Ludenscheidt	82.3	17.5				
Red Vienna	97.8	2.2				
Sheet, Paris	92.	8.				
Sheet, Paris	88.	12.				
Sheet, Paris	84.	16.				
Golden	82.	17.5	0.5			
French	80.	17.	3.			
French	80.	20.				
Cast	87.	13.				
Common	71.5	28.5				
Tournay's	82.54	17.46				
Tubes, etc.:						
German	70.	30.				
German	60.	40.				
Russian	66.	34.				
Russian	59.72	38.62	0.16	0.34	1.1	
English	65.	35.				
Admiralty	70.	29.	1.0			
Turbiston's	55.	41.			0.84	Ni, 2; Al, 1.0; Mn, 0.16
Tungsten Brass (Ni, 0.75)	59.73	33.97	0.15			Al, 2.8; W, 2.; Mn, 0.7
Turbine Brass	75.77	24.07				
Turbine Brass	67.35	32.02		0.23	0.38	
Vanadium Bronze Vn-c	61.	38.5				Va, 0.5
Vanadium Brass	70.	29.5				Va, 0.5
Washer Brass	62.00	38.00				
Wheel Brass	68.00	30.00		2.00		
Wire	70.29	29.26	0.17	0.28		
Wire, English	70.29	29.36	0.28	0.17		
Wire, Augsburg	71.89	27.33		0.85		
Wire, Common	65.4	34.6				

A LIST OF ALLOYS (Continued)

BRONZES

	Cu	Zn	Sn	Pb	P	Other Elements
Acid Bronze	88.00	10.00		2.00		
Acid Bronze	82.00	8.00	2.00	8.00		
• Acid Bronze	84.00	9.50		6.30	0.20	
Ajax Plastic	64.00	5.00		30.00		Ni, 1
Ajax Phosphor	79.30	10.00		10.00	0.7	
Allan Red Metal	50.00			50.00		S, 0.25
Allan Red Bronze	62.50	7.50		30.00		
Amax Metal	81.30	11.00		7.40	0.3	
Argental	85.00	10.00				Co, 5.0
Argozoil	54.	2.	28.00	2.		Ni, 14.0
Arsenic	79.7	10.00		9.50		As, 0.8
Bearing Bronze (Kaiser):						
Locomotive	74.	10.	9.	7.		
Prussian	84.	15.	1.			
Belgian	80.	16.		2.0		Sb, 2
French (Northern)	82.	10.	8.			
Russian	77.	10.2	5.1	7.7		
Railroad Cars	82.	18.				
Railroad Cars	84.	16.				
Railroad Cars	75.	20.	5.			
Rheinland	86.	12.	2.			
E.B.D., Breslau	88.	10.	2.			5 per cent of P Sn
E.B.D., Berlin	90.	10.				
Automobile	88.	8.		3.		1 per cent of P Sn
Automobile	78.	8.	1.	12.		1 per cent of P Sn
Automobile	80.	10.		8.		2 per cent of P Sn
Various	83.	14.	2.	1.		
	83.7	14.2	2.1			
	85.5	12.8	1.7			
	83.	12.	5.			
	85.	11.	4.			
	74.5	9.5	8.9	7.1		
	77.	9.	14.			
	83.7	8.8	7.5			
	84.	8.		8.		
	81.	7.	3.	9.		
	78.	7.		15.		
	70.	6.5	2.	1.5		
	86.	6.	5.			Mn, 2.7
	72.4	4.7	29.9	1.5		
	75.	4.	21.			
Bearings of Engines	79.	8.	5.0	8.0		
Bearings and Valves	80.	16.		2.		Sb, 0.2
Bell Metal	75–80	25–20				
"Best"	78.	22.				
Reichenhall, 600 years	76.2	23.8				
Reichenhall, 300 years	80.	20.				
Old Bell at Rouen	71.	26.	1.8	1.2		
Damstadt	73.94	21.67		2.11		Fe, 0.19; Ni, 2
Damstadt	72.52	21.06		2.14		Fe, 0.05; Ni, 2.66
Musical	84.	16.				
House	80.	20.				
Clock	75.	25.				
Herbohn	60.	35.	5.0			
Herbohn	71.43	26.4	2.7			
Karakane	71.42	14.2		14.3		
Karakane	70.	19.	3.	8.		
Karakane	65.95	17.25	3.45	10.35		
Karakane	64.	24.	9.			Fe, 3.0
Karakane	62.5	25.	9.4			Fe, 3.1
Karakane	61.	18.	6.	12.		Fe, 3.0
Bilgen-Bronze	97.32	1.89		0.24		Fe, 0.52
Bridge Bronze A	80.	20.			0.1	
Bridge Bronze B	85.	15.			0.1	
Bridge Bronze C	80.	10.		10.	0.7–1	
Bridge Bronze D	88.	10.	2.		0.25	
Bismuth Bronze	53.	15.	20.			Ni, 10.; Al, 1.; Bi, 1
Brasses	74.4	9.5	8.9	7.1		
Brasses	70.	10.	10.	10.		
Brasses	74.	1.0	10.	15.		
Bushings	86.2	10.2	3.6			

A LIST OF ALLOYS (Continued)

BRONZES (Continued)

	Cu	Sn	Zn	Pb	P	Other Elements
Bushings	85.	11.	4.			
Camelia	70.4	4.2	10.2	14.7		Fe, 0.5
Carbon	75.4	9.7		14.5		
Carriage Wheel Bearing	84.	16.				
Chinese	72.5	4.7	14.3	18.5		
Chinese	74.	1.0	10.	15.		
Cocks	88.	10-8.	2-6.			
Cogs and Worms	85.	11.	4.			
Coinage	95.	4.	1.			
Cooper's Speçulum	57.8	27.3	3.6			As, 1.2; Pt, 10.
Cornish	77.8	9.6			0.8	
Damascus	77.	10.5		12.5		
Damar	76.4	10.6		12.5		
Daimler Bearing	76.	3.	20.	1.		
Dudley's B	77.	8.		15.		
Dudley's K	77.	10.5		12.5		
Dudley's Phosphor	79.7	10.		9.6	0.8	
Durena	65.	2.	30.			Al, 1.5; Fe, 1.5
Dysoid	62.	10.	10.	18.		
Edward's Speculum	63.3	32.2				As, 1.6
Edward's Speculum	69.8	25.1	2.6			As, 2.4
Eisen-Bronze	82.5	8.55	4.45			Fe, 3.95
Eislers	94.1	5.9				
Eccentric Ring	84.	14.	2.			
File Bronze	64.4	18.	10.	7.6		
File Metal (Genfer)	64.4	18.	10.	7.6		
File Metal (Genfer)	62.	20.	10.	8.		
File Metal (Vogel)	73.	19.	8.	8.		
File Metal	61.5	31.		8.5		
File Metal	51.	28.5	7.	7.		
Flange Metal (German)	92.4	2.5	5.05			
Flange Metal (French)	94.35	5.6		0.05		
Gearing	91.3	8.7				
Gear Bronze	88.	10.			2.	
Gear Bronze	85.	13.	2.			
Gears	85.	10.	3.	2.		
Gun Metal	90.	10.				
French, Modern	90.1	9.9				
French, Old	89.44	8.91	1.39	0.16		
Prussian, Modern	90.9	9.1				
English, Modern	89.3	10.7				
English, Modern	91.74	8.26				
Russian ,Modern	90.8	9.2				
Russian, 1813	88.61	10.7				Fe, 0.69
Swiss (Lucern)	88.93	10.37	0.42			
Cochin China	77.18	3.42	5.02	13.22		Fe, 1.16
Cochin China	93.19	5.43				Fe, 1.38
Chinese, Old	71.16		27.36			Fe, 1.40
Chinese, 1901	93.2	5.05				Fe, 1.72
Turkish, 1464	95.2	4.31				
Turkish, 1907	90.9	8.8				Fe, 0.2
Gun Mount	80.	3.	17.			
Graney Bronze (Law)	75.8	9.2	15.			
Gurney's	75.8	9.2	15.			
Hercules	85.5	10.	2.			Al, 2.5
High Temperature	90.7	2.7	6.3	1.3		
Hydraulic	83.0	10.8	6.0	0.1		
Instrument	82.	13.	5.			
Instrument	82.1	12.8	5.1			
Johnson Locomotive Bearing	87.5	7.85	5.07			
Kern's Hydraulic	78.	12.	10.			
Kochlin's Bearing	90.	10.				
Kuhne Phosphor Bronze	78.	10.6		10.45	0.57	Ni, 0.26
Lafond's Bronze	83.	15.	1.5	0.5		
Lafond's Axle Bearing	80.	18.	2.			
Lafond's Straps	84.	14.	2.			
Lafond's Pumps	88.	10.	2.			
Lafond's Heavy Bearing	83.	15.	1.5	0.5		
Lafond's Malleable	98.04	1.96				
Lowroff Phosphor Bronze	70.	13.		16.	1.	
Lowroff Phosphor Bronze	90.	4.		5.5	0.5	

A LIST OF ALLOYS (Continued)

BRONZES (Continued)

	Cu	Sn	Zn	Pb	P	Other Elements
Laderig's Speculum	69.	28.7				
Medal	92.	8.				
Medal	97.	1.	2.			
McKechnie's	57.	41.	1.	0.5		Fe, 1.
Manheim Gold	83.7	7.	9.3			5 per cent of Phos. Tin
Manganese Bronze	82.	8.	5.	3.		Mn, 2.0
Manganese Bronze	83.5	8.	5.	3.		Mn, 0.5
Mudge's Speculum	68.82	31.18				
Needle	84.5	8.	5.5	2.		
Nongran	87.	11.	2.			
Neogen	58.	2.	27.			Ni, 12.; Al, 0.5; Bi, 0.5
Naval Gun Metal, G	88.	10.	2.			
Naval Journal, H	83.	13.5	3.5			
Naval Journal, HX	83.	13.5		3.5		
Naval Valve, M	87.	7.	6.			
Naval Phosphor, Cast, P-c	88.	8.	2.5		0.5	
Naval Phosphor, Rolled, P-r	95.	4.5			0.5	
Oil Cups	85.	5.	7.			
Oil Pump	83.	3.	9.		3.	
Ounce Metal	85.	5.	5.	5.		
Ormulu	58.	16.7	23.3			
Ormulu, small	94.12	5.88				
Ormulu, large	90.5	6.5	3.0			
Perking Brass	76.2	23.8				
Perking Brass	80.	19.82	0.14			
Phosphor Bronze:						
Wire	98.75	1.2			0.05	
Hard	92.8	7.			0.2	
Very Hard	80.	9.			1.0	
Rolling	95.6	4.5			0.1	
Charpy	85.7	12.2			0.4	
Charpy	84.8	13.4			0.46	
Law	87.6	10.8			1.0	
Law	88.7	9.5			0.7	
Bridge	80.	20.			1 0.2	
Bridge	85.	15.			1.	
Bearings	83.	14.	2.	1.	1.	
Bushings	79.	10.		10.	0.7	
Gears	88.	10.		2.	0.1	
Gears	85.	13.	2.		0.1	
Gears	78.	12.		7.5	0.1	
English	79.2	10.2		9.6	0.97	
Pennsylvana iRailroad	79.7	10.		9.5	0.8	
Pennsylvania Railroad "B"	76.8	8.		15.	0.2	
Pennsylvania Railroad "B"	85.55	9.85	3.77	0.62	0.05	
Pennsylvania Railroad "B"	80.	8.		10.		2 per cent of Phos Tin
Russian	93.7	5.8	0.34		0.17	
Piston Rings	84.	2.9	8.3	4.3		
Piston	83.	1.	16.			
Railroad (Hughes):						
Slide Valves	84.5	10.		5.	0.5	
Injector	84.	8.5	5.	2.5		
Phosphor Bronze	88.5	10.			0.5	
Axle Box Bearing	80.	5.		15.		
20-Ton Wagon	60.	5.		20.		
Railroad (Thurston):						
Axle Bearings, French	82.	10.	8.			
Axle Bearings, Common French	78.	20.	2.			
Axle Bearings, Lafond	80.	18.	2.			
Axle Bearings, Hard	87.05	7.88	5.07			
Eccentric Strap, Dutch	85.25	12.75	2.0			
Eccentric Strap, Lafond	84.	14.	2.0			
Gearing	88.8	8.5	2.7			
Locomotive Bearings	89.	2.4	7.8			Fe, 0.8
Locomotive, German	81.17		15.2	14.6		Fe, 0.9
Locomotive, Durable	73.5	9.5	9.5	7.5		Fe, 0.5
Pistons and Rods	74.1	3.7	22.2			
Richardson's Speculum	65.3	30.	0.7			As, 2.0; Si, 2.
Roman Bronze	90.	9.				
Ross' Alloy	68.2	31.8				

A LIST OF ALLOYS (Continued)

BRONZES (Continued)

	Cu	Sn	Zn	Pb	P	Other Elements
Sallit's Speculum	64.6	31.3				Ni, 4.1
Sheet Bronze	90.	10.				
Sheet Phosphor	94.5	5.0				0.5 per cent of Phos. Tin
Sheet Phosphor	95.	4.				1.0 per cent of Phos. Tin
Sashchain	92.	8.				
Sashchain	95.	5.				
Screw-Nut	86.	11.4	2.3			
Slide Valve	88.5	2.5	9.			
Steam Fittings	88.	8.	2.	2.		
Silicon Bronze	98.55	1.45				Si, 0.05
Silicon Bronze	91.	9.				Si, 0.05
Statuary Bronze:						
Column Vendome	89.2	10.2	0.5	0.1		
Column of July, Paris	91.4	1.6	5.6	1.4		
Napoleon I, Paris	75.0	3.0	20.	2.0		
Henry IV, Paris	89.62	5.7	4.2	0.48		
Louis XIV, Paris (1699)	91.4	1.7	5.53	1.37		
The Shepherd, Potsdam	88.68	9.2	1.28	0.77		
Bacchus, Potsdam	89.34	7.5	1.63	1.21	0.18	
Germanicus, Potsdam (1820)	89.78	6.16	2.35	1.33		Ni, 0.27
Mars and Venus, Munich	94.12	4.77	0.3	0.67		Ni, 0.48
Bavaria, Munich	91.55	1.77	5.5	1.3		
Munich	92.88	4.18	0.44	2.31	0.15	
Munich	77.03	0.91	19.12	2.29	0.12	Ni, 0.43
Augsburg	89.43	8.17		1.05	0.34	Ni, 0.19
Augsburg	94.74	1.64	0.54	6.24		Ni, 0.71
Grosser Kurfürst, Berlin	89.09	5.82	1.64	2.62	0.13	
Frederick the Great, Berlin	88.3	1.4	9.5	0.7		
Melanchron, Wittenberg	89.55	2.99	7.45			
Speculum, Cu_4Sn	68.25	31.75				
Speculum, English	66.6	33.4				
Speculum, Chinese	80.8	10.7				Sb, 8.5
Speculum, Chinese (Elsner)	80.8					Pb, 9.1; Sb, 8
Schmidt Locomotive Bearing	86.	14.				
Seraing Bearing	86.	14.				
Seraing Piston Rings	89.	2.	9.			
Stephenson, Locomotive Bearing	79.5	7.5	5.0	8.0		
Stephenson, Piston Rings	84.	2.9	8.3	4.3		Fe, 0.4
Stone's English Gear	89.	11.				
Telegraph Bronze	80.	5.	7.5	7.5		
Tungsten Bronze	90.					W, 10.
Tin Bronze	89.	11.				
Uchatius Bronze	92.	8.				
Ulcony	65.			35.		
Valves	85.	9.	6.			
Valve Bronze	89.	5.	3.	3.		
Valve Bronze	83.	4.	7.	6.		
Valve, Steam	88.	10.	2.			
Weights	90.	8.	2.			
Whistles	80.	18.	2.			
Whistles, Lafond	81.	16.	2.			
Whistles, Lafond	80.	18.				Sb, 2.0
Wire	98.75	1.2			0.05	

COPPER-NICKEL ALLOYS

	Cu	Ni	Other Elements
Locomotive Tubes	97.	3.	
Driving Bands, Sheet	95.	5.	
Benedict Metal, Sheet, Tubes	86-84	14-16	
Blanko-Blech	80.	20.	
Cupro-nickel, Sheet	81-79	19-21	
Imperial Metal	80.	20.	
Turbine Material	79-81	21-19	Fe, 0.75 max.
Coinage	75.	25.	
Constantin, Resistance	60.	40.	
Constantin, Resistance	54.	45.	Mn, 1.0
Ingots for Nickel Silver	50.	50.	
Monel Metal, cast	28.	68.	Fe, 2.; Si, 1.; Mn, 0.25
Monel Metal, forged	28.	68.	Fe, 2.; Mn, 1.5; Si, 0.20

A LIST OF ALLOYS (Continued)

NICKEL SILVER

(Agiroide, Alfenide, Argentan, Arguzoid, Argyrolith, Electrum, Neusilberg, Nickelin, Maillechort, Packfong, Sterlin, Tutenag, White Copper, etc.)

	Cu	Zn	Ni	Fe	Sn	Pb	Other Elements
Albatra Metal	57.5	22.5	18.75			1.25	
Ambrac	74.5	5.0	20.0				Mn, 0 50
Argentan:							
Sheet	40-65	17-32	15-20				
Chinese	40.4	25.4	31.6	2.6			
French	50.32	30.94	18.4				
Berlin	55.5	29.1	15.5				
Vienna	55.6	21.8	22.2	0.38			
English	63.36	17.01	19.13	0.38			
Russian	63.88	17.58	17.58	0.33		0.32	
Castings, Berlin	48.32	23.8	24.15	3.61			
Castings, Russian	57.52	18.94	20.35	3.15			
Solder	35.	57.	8.				
Alpakka	63.94	19.24	14.55	0.4	0.12	0.03	Ag, 2.02
Aluminum Silver	57.	20.	20.				Al, 3.0
American Silver, Cast	49.36	20.7	24.2	1.3	0.45		Mn, 3.83; Al, 0.13
American Silver, Cast	57.7	24.2	15.3	0.6	0.69	1.5	
American Silver, Cast	59.11	22.66	11.22			2.9	Al, 1.5; P Sn, 5.0
Aphit	70.	5.5	20.				Cd, 4.5
Aphit	75.1	2.37	20.75				Cd, 1.8
Arguzoid	55.78	23.2	13.4		4.03	3.54	
Aterite, Cast	66.75	17.25	13.92	1.58		0.18	Mn, 0.23; Al, 0.17
Aterite, Rolled	67.76	19.97	12.36	1.51		0.07	Mn, 0.16
Aterite, Rolled	46.96	38.	10.82	1.9			Mn, 2.24
Benedict Plate	57.	28.	15.				
Back Case Metal	62.	20.	18.				
Bismuth Bronze	45.	21.5	32.5		16.		Bi, 1.
Bismuth Bronze	53.	20.	10.		15.		Bi, 1.; Al, 0.1
Bismuth Brass	47.	21.	30.9		1.		Bi, 1.
Bismuth Brass	52.	12.	30.			5.	Bi, 1.
Brazing Solder	35.	57.	8.				
Brazing Solder	45.	45.	10.				
Carbondale	66.	16.	18.				
Casting	55.8	23.7	13.4		4.	3.5	
Casting	69.9	5.6	19.8				Cd, 4.7
Colorado Metal	57.	18.	25.				
Christofle Metal	(Silver	-plated	German	Silver			Ag, 2.0
Chromax Bronze	66.7	12.1	15.2				Al, 3.; Cr, 3.
Cupping and Milling	58.	21.5	20.			0.5	
Drawing and Spinning	58.66	29.33	12.				
English	81.3	19.1	19.1				
Eighteen Per Cent	65.	17.	18.				
Electrum	51.61	22.58	25.81				
Fifteen Per Cent	56.66	28.33	15.				
Fourteen Per Cent	60.	26.	14.				
Fourteen Per Cent	56.	28.	14.				
Flat Ware Stock	53.	26.	21.				
Frick's Alloys	55-50	31-30	19-17				
Bluish-Yellow, Hard	55.50	39.00	5.50				
Pale Yellow, Ductile	62.50	31.20	6.30				
Fricke's Silvery	50.00	18.80	31.20				
Fricke's Harder	69.00	30.00	10.00				
German Silvers:							
Best	46.	34.	20.				
Common Formula	55.	25.	20.				
Austrian Tableware (Gersdorf)	50.00	25.00	25.00				
Austrian Tableware (Gersdorf)	55.60	22.20	22.20				
Austrian Malleable (Gersdorf)	60.00	20.00	20.00				
Berlin Alloy	54.	28.	18.				
Richest	52.00	26.00	22.00				
Medium	59.00	30.00	11.00				
Lowest	63.00	31.00	6.00				
Birmingham (Hiorns):							
Extra White Metal	50.	20.	30.				
White Metal	54.	22.	24.				

A LIST OF ALLOYS (Continued)

NICKEL SILVER (Continued)

	Cu	Zn	Ni	Fe	Sn	Pb	Other Elements
German Silvers (*Cont.*)							
Birmingham (*Cont.*)							
Arguzoid	48.5	31.	20.5				
Best Best	50.	29.	21.				
Special Firsts	56.	27.	17.				
First Bests	56.	28.	16.				
Seconds	62.	24.	14.				
Thirds	56.	32.	12.				
Special Thirds	56.5	32.5	11.				
Fourths	55.	35.	10.				
Fifths, for Plate	57.	36.	7.				
French Alloy (Arcet)	50.00	31.30	18.70				
French Alloy (Arcet)	50.00	30.00	20.00				
French Alloy (Chaval)	58.30	25.00	16.70				
Russian	56.2	23.36	20.4				
Russian	51.4	22.32	26.22				
Russian	46.1	18.	35.8				
Sheffield:							
Common, Yellow	59·30	25.90	14.80				
Silver, White	55.20	24.10	20.70				
Electrum, Bluish	51.60	22.60	25.80				
Hard Alloy	45.70	20.00	31.30				
Key Stock	60.	26.	12.			2.	
Key Stock	65.	22.	12.			1.	
Knife Bolsters	68.	16.50	15.			0.5	
Knife Bolsters	56·	28.	16.				
Maillechort, Paris	66.24	13.42	13.42	3.21	0.22	0.15	
Maillechort, Vienna	66.6	13.6	19.3	0.48			
Maillechort	65.4	13.4	16.8	3.4			
Mangan-Neusilber	59.	20.	18.				Mn, 3
Mangan-Neusilber	65.	5.	10.				Mn, 20.
Mangan-Neusilber	72.25	8.75	16.57				Mn, 2.43
Milling	56.	31.	12.			1.	
Milling	56.5	28.	15.			0.5	
Milling	56.	27.5	16.			0.5	
Milling	54.	27.5	18.			0.5	
Naubuc Knife Stock	58.	16.25	25.	0.75			
Neogen	58.0	27.	12.		2.		Bi, 0.5; Al, 0.5
Nickel Bronze	60.	12.	20.		8.		
Nickel Bronze	47.		3.		10.		PSn, 1.0
Nickel Bronze	47.	21.	30.9		1.		Bi, 0.1
Nickel Bronze	50.	18.	12.		2.	18.	
Nickel Bronze	61.5	10.95	13.35		1.88	10.15	
Nickel Brass	50.00	34.9	15.				Al, 0.1
Nickel Bearing	50.		25.		25.		
Nickelin	55.3	13.1	31.07	0.43		0.18	
Nickel Oreide	65.50	32.66	2.				
Nickel Oreide	64.	32.	4.				
Nickel Oreide	63.33	31.66	5.				
Nickel Oreide	86.66	6.66	6.66				
Nickel Oreide	63.33	30.66	6.				
Optical Wire	54.	28.	18.				
Optical Wire	55.	27.	18.				
Packfong	40.4	25.4	34.6	2.6			
Packfong	26.3	36.8	36.8				
Packfong	43.8	15.6	40.6				
Platinoid	54.00	20.40	24.77	0.47		0.15	Mn, 15.
Platinoid	60.	24.	14.				W, 1-2
Resistance Wire	56.50	25.50	18.				
Rheotan	52.	18.	25.	5.			
Rolling	49.	39.	12.				
Seawater Bronze	45.	5.5	32.5		16.		Bi, 1.
Silvel, Cast	67.93	15.84	6.52	2.22		0.48	Mn, 6.8; Al, 0.13
Show-case Metal	58.	24.	18.				
Show-case Metal	59.50	22.50	18.				
Sheffield	57.	24.	19.				
Sheffield	63.34	17.01	19.13				
Sheffield	62.63	26.65	10.85			0.2	
Sheffield	54.7	37.2	17.1				
Sheffield	57.4	26.5	13.0			3.0	
Smitter-Lenian	72.	9.75	12.75	2.	2.25		Bi, 1.

A LIST OF ALLOYS (Continued)

NICKEL SILVER (Continued)

	Cu	Zn	Ni	Fe	Sn	Pb	Other Elements
Spoons, Forks, etc	60.	22.	18.				
Sterlin	68.52	12.84	17.88			0.76	
Sterline	68.	13.25	18.	0.75			
Suhler White Copper	40.4	25.4	31.6			2.6	
Ten Per Cent	56.	34.	10.				
Ten Per Cent	60.	30.	10.				
Ten Per Cent	62.	28.	10.				
Tuc-Tur, Rod	61.2	20.9	17.6	0.3			
Tuc-Tur, Sheet	58.6	28.5	12.5	0.3			
Turbine Bushing	61.5	10.95	15.35		1.9	10.15	
Tutenag	43.8	40.6	15.6				
Tutenag	45.7	36.96	17.33				
Tutenag	44.	16.	40.				
Toucas	35.75	7.14	28.56	7.14	7.14	7.14	Sb, 7.13
Tungsten Brass	60.	22.	14.				W, 4.
Turning	58.50	29.00	12.00			0.5	
Turning	65.	22.	12.			1.	
Twenty Per Cent	53.33	26.66	20.				
Twenty Per Cent	57.	23.	20.				
Twenty Per Cent	62.	18.	20.				
Twenty Per Cent	64.	16.	20.				
Twenty-one Per Cent	57.	22.	21.				
Twenty one Per Cent	59.	20.	21.				
Thirty Per Cent	46.66	23.33	30.				
Thirty Per Cent	54.	16.	30.				
Victor Metal	49.94	34.27	15.4	0.28			Al, 0.11
Viennese Sheet	60.	20.	20.				
Viennese Ornaments	55.	25.	20.				
Viennese Tableware	50.	25.	25.				
Wagner's Formula	50.66	19.31	13.18				
Watch-case Bezels	60.	24.	16.				
Watch-case Bezels	63.	21.	16.				
Wessels Silver	51.	17.	32.				
White Copper	70.	18.	12.				
White Alloy	48.8	24.4	24.4	2.4			
White Alloy	53.0	23.0	22.0	2.0			

ALUMINUM BRONZES, ETC.

	Cu	Al	Fe	Zn	Ni	Other Elements
Aluminum Brass	63.	3.33		33.66		
Aluminum Brass	67-71	1.25-3.5		31.75-25.5		
Aluminum Bronze, Percy	90.	10.				
Aluminum Bronze, Percy	86-89	12.5-7.5				Mn, 0.5-1.5; Pb, 1-2
Aluminum Silver	57.	3.		20.	20.	
Aluminum Iron Bronze H	89.43	6.97	3.41			
Aluminum Iron Bronze R	88.16	6.6	7.52			Mn, 0.5
Aluminum Iron Bronze S	85.15	9.43	4.74			Pb, 0.38; P, 0.09
Aluminum Magnesium Bronze	94.5-89.5	5-10				Mg, 0.5
Aluminum Manganese Bronze	89.12	9.6				Mn, 1.2
Aluminum Nickel Bronze	85.	5-10			10-5	
Aluminum Tin Bronze	85.5	2.5		2.		Sn, 10.
Aluminum Titanium Bronze	90-89	9-10	1.0			Ti, trace
Ampco	Bal.	7-11	1-3			
Cowles Aluminum Bronze	88.4	9.74	0.43			Si, 1.36
Cowles "A", Special A	89.	11.				
Cowles A 1, 2, 3	80.	10.				
Cowles B	92.5	7.5				
Cowles C 1	94.5	5.5				
Cowles C 2, 3	95.	5.				
Cowles D	97.5	2.5				
Cowles E	98.75	1.25				
Cupror	94.2	5.8				
Dirigold	(See O	ranium	Bronze)			
French (Fe Ni Mn)	81.5	7.	4.		5.5	Mn, 2.

A LIST OF ALLOYS (Continued)

ALUMINUM BRONZES ETC. (Continued)

	Cu	Al	Fe	Zn	Ni	Other Elements
Emperor Brass	60.	20.		20.		
Heusler's Alloy	66.5	11.1				Mn, 22.4
Heusler's Alloy	68.	10.				Mn, 18; Pb, 4.
Heusler's Alloy, Max	61.	13.				Mn, 26.
Hercules Metal	85.5	2.5		2.		
Hercules Metal	54.	2.5	7.5	36.		
Immadium Bronze	(Manganese Bronze with Aluminum)					
Metaline	30.	25.	10.			Co, 35.
Navy	85-87	7-9	2.5-4.5			
Oranium Bronze S	97.	3.				
Oranium Bronze M	95.	5.				
Oranium Bronze MH	91.5	8.5				
Oranium Bronze H	90.	10.				
Oranium Bronze HX	89.	11.				
Oranium Bronze HH	88.5	11.5				
Rakel's Metal	87.5	10.5		1.		Mn, 1.
Roberts-Austen (Purple Gold)		21.5				Au, 78.5
Reichs Bronze	85.15	0.6	7.5			Mn, 0.5
Secretan	91-95	9-5				Mg, 1.5; P, 0.5
Superbronze	56.8	1.2	1.3	37.5		Mn, 3.2
Superbronze	68.9	5.1	2.0	20.9		Mn, 3.0
Tensilite	64.	3.1	1.2	29.		Mn, 2.5; Sn, 0.2
Tensilite	67.	4.4		24.		Mn, 3.8
Tetmajer	86.1	10.	0.98			Si, 2.48
Tetmajer	89.7	7.1	0.72			Si, 2.72
Tetmajer	93.3	4.6	0.89			Si, 0.98
Typewriter Metal	57.	3.		20.	20.	

COPPER-MANGANESE ALLOYS

	Cu	Mn	Fe	Zn	Sn	Ni	Other Elements
Cupro-Manganese	90.	10.	0.				
Crotorite	70.	30.	2.				
Resistance, Lunge	86.5	11.7	1.8				
Resistance, Lunge	84.32	13.43	1.9				
Resistance Metal	85.	12.	3.				
Manganese Copper	29.2	51.65	9.68				Al, 6.25
Manganese Copper	56.3	40.9	1.5				Si, 1.1
Manganese Copper	75.	25.					
Manganese Copper	75.3	22.4	2.15				
Manganese Copper	85.	10.92	1.83	2.0			C, 0.26
Manganese Copper	85.55	10.66	2.66		0.39		Pb, 0.45
Manganese Copper	84.33	10.61	2.31	2.1	0.4		Pb, 0.3
Manganese Copper	89.7	8.72	1.54				
Manganese Brass	54.2	4.4	2.4	38.2		0.5	
Manganese Brass	55.	4.3	0.7	39.5			Al, 0.5
Manganese Brass	51.15	4.15	2.25	40.		2.2	Al, 0.25
Manganese Brass	53.51	3.24	1.44	38.28	1.22	2.14	
Manganese Brass	55.4	3.2	1.06	39.9			Al, 0.2
Manganese Brass	60.15	2.34	1.19	34.9	0.94		Al, 0.23; Pb, 0.39
Manganese Brass	53.4	1.7	0.	39.	2.66	2.5	Al, 0.2
Manganese Brass	53.5	1.53	2.78	39.		2.53	
Manganese Brass	69.5	1.0		29.5			
High Manganese Brass:							
Ponsard's	50.	24.	16.	10.			
Ponsard's	60.	25.		15.			
Ponsard,s	75.	20.		2.			
Cowles	67.5	18.		13.			Al, 1.; Si,. 05
Cowles	75 5	16.5		8.			
Cowles	80.	15.		5.			
Rheotan	84.	12.		4.			
Manganese Bronze	82.4	0.6			17.		
Manganese Bronze	85.75	0.25			14.		
Manganese Bronze	86.3	2.7		5.	6.		
Manganese Nickel Silver	72.5	2.43		8.75		16.57	

A LIST OF ALLOYS (Continued)

COPPER-MANGANESE ALLOYS (Continued)

	Cu	Mn	Fe	Zn	Sn	Ni	Other Elements
Manganese Nickel Silver	65.	20.		5.		10.	
Manganese Nickel Silver	60.	20.			10.	10.	
Manganin	86 84	12.				2-4	
Manganin	84.	4.				12.	
Manganese Nickel	78.3	14.1				7.6	
Manganese Nickel	82.12	15.02	0.6			2.3	
Manganese Nickel	73.	24.				3.	
Manganese Nickel	70.	25.				5.	
Manganese Nickel	65.	30.				5.	
Manganese Nickel	51.5	31.3				16.2	
Silvel	73.3	12.	1.8	12.1			Al, 0.25; Pb, 0.51
Silvel	67.9	6.8	2.22	15.8		6.5	Al, 0.13; Pb, 0.48
Heusler's Magnetic Alloys	70	30.					Al, 8-14.5
Heusler's Magnetic Alloy, max	61.	26.					Al, 13.
Heusler's Magnetic Alloy	66.5	22.4					Al, 11.1
Heusler's Magnetic Alloy	68.	18.					Al, 10; Pb, 4.
Tubes	96.	4.					

ALUMINUM ALLOYS

	Al	Cu	Zn	Mn	Mg	Ni	Fe	Si	Other Elements
Acieral:									
Sheet	Bal.	2.3		1.5	0.1		1.4		
Sheet	Bal.	3.7		1.0	0.2		1.3		
Sheet	Bal.	3.8		1.0	0.5		0.7		
Cast	Bal	6.4	0.4			0.90	0.1	0.4	
Cast	91.87	5.7			0.12	0.98	0.94	0.39	
Aero Metal:									
Sheet	Bal.	0.6		0.14	2.1		1.3		
Sheet	Bal.	0.2			2.9		0.3	0.4	
Cast	Bal.	4.2	27.8				0.5	0.5	
Aluminite Cast	Bal.	2.7	23.3				0.4	0.2	
Aluminum Silver	95.00								Ag, 5.
Bell Metal	83.00			10.					Cd, 7.
Bourbonnes	48.8	0.25					0.33		Sn, 50.48
Bersch Bearing	93.					7.			
Duralumin	Bal.	3.5 5.5		0.5 0.8	0.5				
Duralumin	Bal.	4.2		0.49	0.76		0.67	0.34	
Durand's	66.6		33.3						
Die Casting	92. 82.	8. 18.							
Die Casting	86.13	10.17	0.24	0.03	0.32		2.81	0.3	
Fletcher and Emperer Bearing	92.2	7.5							Sn, 0.25
Fletcher's Alloy	95.5	3.							Sn, 1; Sb, 05, PSn, 5
Hard Aluminum	77.		11.5		4.5				
Huron:									
Castings A-5	Bal.	6.6			0.5	1.25			Co, 0.25 and (Mn Sn Cd, 0.5)
Rolled A	Bal.	3.5		0.6	0.5				Cr, 0.1
Rolled B	Bal.	4.0		0.6	0.5				Cr, 0.1
Rolled D	Bal.	4.0			0.5				Cr, 0.6
Ingots:									
Casting 11	88.85	6.6	2.3	1.		1.25			
Casting 12	92.	8.							
Casting 21	90.	10.							
Casting 22	83.7	6.3	5.						Sn, 5.
Casting 31	80.5	3.	16.	5.					
Casting 32	64.		36.						
Casting 33	81.		19.						

A LIST OF ALLOYS* (Continued)

ALUMINUM ALLOYS (Continued)

	Al	Cu	Zn	Mn	Mg	Ni	Fe	Si	Other Elements
Ingots (*Continued*)									
Casting 34	78.		22.						
Rolling 3.5	98.5			1.5					
Rolling 5.5	94.5	2.	2.	1.5					
Rolling 8.5	66.6		33.3						
Krupp (Grosmann) Bearing	87.	8.							Sn, 5.
L-5	Bal.	2.5-3.0	12.5-14.5						
Liberty Piston	76.6	1.06	21.3				0.47		Pb, 0.33; Sn, 0.12
Lynite:									
146	Bal.	7.00-8.5							
122	Bal.	9.25-10.75							
109	Bal.	11.5-13.5							
Crank Case	Bal.	7.8	1.5				1.25		
Body Alloy	Bal.	5.							
Piston	89.	11.			0.5				
Piston	95.3	2.14		0.07	1.5		0.76	0.23	
Mach's	Bal.				2-10				
Magnalium:									
Cast x	Bal.	1.76			1.6	1.16			
Cast y	Bal.	1.75			1.5				Sn and Pb
Cast z	Bal.	0.21			1.58				Sn, 3.15; Pb, 0.7
Cast	85.00				15.00				
Sheet	95.				5.				
	Bal.		1-20		1-10				
Magnalite	Bal.	2.			2.	2.			
Magnalite	Bal.	2.5	0.5		1.3	1.5			
Magnalite	93.09	2.19			1.54	1.45	1.10	0.61	
Magnalite	94.27	2.47	0.13		1.17	0.65	0.69	0.59	
Magnalite	93.5	2.61			1.37	1.72	0.86	0.37	Sn, 0.17
Magnalite	93.9	2.4			1.56	1.19	0.47		
Magnalite	93.2	2.44			1.38	1.25	1.35	0.37	
Manhardts	83.33	6.24			0.05				Sn, 10.; P, 0.07
Maluminum	Bal.	6.4	4.8	0.1			1.4	0.2	Pb, 0.15
McKinney:									
Cast	96.	2.		1.5					
Forging, Soft	96.5	2.		1.0					
Forging, Hard	94.5	3.		2.					
McAdamite		3.1	12-18		0 2				
McAdams, W. A.	68.5	7.7	23.1			0.63			
McAdams, W. A.	60.	5.	20.						Ag, 16.5
McAdams, W. A.	70.	3.	26.						Ag, 1.
McAdams, W. A.	70.	3.	22.						Sb, 5.
McAdams, W. A.	100.	5.							Ag, 2.
McAdams, W. A.	80.								Sn, 8.; Cd, 8.; Ag, 4.
McAdams. W. A.	82.	12.							Cd, 5.; Ag, 1
McLure	Bal.	8.2		0.2			0.9	0.3	Sn, 5-6
Metalline	25.	30.					10.		Co, 35.
Meteorite	Bal.		1-2						P, 1-4
Mock Silver	84.2	5.5							Sn, 10.2; P, 0.1
Murman's	92.		4.4		3.6				
Murman's	72.		14.5		13.5				
Navy	Bal.	1.5		0.9		0.4	0.4	0.3	
Partinium	Bal.	0.64							Sb, 2.4; Sn, 0.16; W, 0.8
Partinium	88.5	7.4	1.7				1.3	1.1	
Pistons	93.3	3.39			1.39		1.46	0.45	
Pistons	93.5	2.45	0.28		1.47	1.47	0.4	0.4	
Platinum Substitute	23.6					0.72			Bi, 3.7; Au, 0.7
Romanium	Bal.	0.25				1.75			Sb, 0.25; Sn, 0.15; W, 0.17
Rosein	30.					40.			Sn, 20.; Ag, 10.
Rosenhain and Archutt Forging	72.	3.	25.						
Sibley Alloy	67.		33.						
Susini	Bal.	1.5	0.5	1-3					
Susini	Bal.	2.5	1.0	1-5					
Susini	Bal.	4.5	1.5	2-8					
T. Metal	Bal.	0.1			3.8		0.5	0.5	
Tiers Argent	66.								Ag, 33.

A LIST OF ALLOYS (Continued)

ALUMINUM ALLOYS (Continued)

	Al	Cu	Zn	Mn	Mg	Ni	Fe	Si	Other Elements
Verilite	Bal.	2.5		0.3			0.7	0.4	
Wolframium	98.	0.36					0.22		Sb, 1.4; W, 0.05
Wolframium	98.	0.375							Sb, 1.44; Sn, 1; W, 0.04
W. 0. 33	Bal.	14.		1.					
Zeppelin Alloys:									
Rod	94.58	4.16		0.62			0.42	0.52	
Braces	99.1	0.06	0.13				0.38	0.36	
Channels	88.68	0.7	9.1	0.45			0.43	0.49	Sn, 0.15
Angles	90.27	0.73	7.8	0.27			0.45	0.37	Sn, 0.11
Zimalium	93.5		2.8		3.7				
Zimalium	91.		4.5		4.5				
Zimalium	88.5		4.4		7.1				
Zimalium	74.		14.8		11.2				
Zisium	83.	1.	15.						Sn, 1.
Zisium	82.	3.	15.						
Ziskon	60.		40.						
Al-Cu, Strongest	Bal.	3.75							
Al-Cu	91.66	7.16					0.85	0.33	
Al-Cu	91.62	7.57	0.1	0.07			0.43	0.22	
Al-Cu-Ni	Bal.	2.				5.25			
Al-Cu-Ni	Bal.	4.1				1.1			
Al-Cu-Zn Strong:									
Cast	80.	5.	15.						
Forged	75.	3.	22.						
Centrifugal Cast	80.	3.	17.						
Ingot	82.7	3.15	12.8	0.39			0.48	0.19	Pb, 0.19; Sn, 0.12
Ingot	82.8	5.52	9.9	0.18			0.81		Pb, 0.3; Sn, 0.27
Casting	83.55	4.87	11.1	0.06			0.19	0.27	
Al-Cu-Mg Casting	93.6	3.61			2.23		0.31	0.28	
Al-Cu-Mg Casting	93.	3.65			2.25		0.60	0.38	
Al-Cu-Mg Casting	91.9	3.37		0.55	3.5		0.38	0.29	
Al-Cu-Mg Casting	95.5	4.			0.5				
Al-Ni-Ti	97.6					2.0			Ti, 0.4
Al-Ni-Zn	85.		5.			10.			
Va Alloy	80.2	5.01	13.7				0.72		V, 0.2
W Alloy	82.1	12.32	4.5						W, 1.0
Alloys Research Committee:									
"Y" Casting	82.5	4.			1.5	2.			
"A" Forging	77.	3.	20.						
"E" Rolling	76.	2.5	20.	0.5	0.5		0.2	0.2	

TIN BASE ALLOYS

	Sn	Sb	Cu	Pb	Other Elements
Algiers Metal	94.5	0.5	5.		
Algiers Metal	90.	10.			
Algiers Metal	75.	25.			
Ashberry Metal	80.	14.	2.		Zn, 1.
Ashberry Metal	79.	15.	3.		Zn, 2.
Ashberry Metal, Brittania	77.8	19.4	2.8		
Ashberry Metal, Brittania	77.9	19.4			Zn, 2.8
Argentin	85.	14.5	0.5		
Aluminum Solder	85–50				Zn, 15–50
Burgess	76.				Zn, 21; Al, 3.
Frismuth	67.			27.	Al, 3.
Grimm's	69.1			28.8	Zn, 1.44; Ag, 0.72
Grimm's	50.			25.	Zn, 25.
Aluminum, Wegner and Guhr's	80.				Zn, 20.
Aluminum, Wilmotts	86.				Bi, 14.
Aluminum, Various	Bal.				Zn, 8–15; Al, 5–12.
	50.			33.3	Zn, 66.6
	47.5			47.5	Ca, 5.
	49.5	3.43	1.1	26.06	Zn, 20.31
	85.				Al, 10.; P Sn, 5.

A LIST OF ALLOYS (Continued)

TIN BASE ALLOYS (Continued)

	Sn	Sb	Cu	Pb	Other Elements
Babbitts,Original	89.	7.3	3.7		
Babbitts, Hard	83.3	8.3	8.4		
Bearing:					
Navy	89.	7.3	3.7		
Navy	91.	4.5	4.5		
Prussian	91.	6.	3.		
Prussian	90.	6.	4.		
Russian Railroad	90.	8.	2.		
Automobile, American	89.	7.	4.		
Automobile, American	89.3	8.9	1.8		
Automobile, American	88.9	7.4	3.7		
Automobile, American	87.	7.	6.		
Heavy	85.	7.5	7.5		
French Car	83.3	11.1	5.5		
German Railroad	83.	11.	6.		
Valve Rods, etc	82.	10.	8.		
French Railroad	82.	12.	6.		
Piston	81.	12.5	6.5		
Swiss Railroad	80.	10.	10.		
English	76.7	18.5	7.8		
German	76.	7.	7.		
Prussian	74.	15.	11.	10.6	Zn, 0.18: Fe, 0.22
Prussian	73.	18.	9.		
Prussian	72.	26.	2.		
(Kamarsch)	71.4	7.2	21.4		
Valve Packing	71.	24.	5.		
German	70.8	15.1	4.9	9.2	
(Kamarsch)	70.7	19.7	9.5		
G. W. R. England	67.	11.	22.		
French Railroad	67.	22.	11.		
English Railroad	90.	7.	3.		
German Ludenscheidt	71.8	24.3	3.85		
Brittania:					
English	94.	5.	1.		
English	90.	6.	2.		Bi, 2.
English	90.	7.	3.		
English	85.5	9.7	1.8		Zn, 3.
Cast	90.6	9.2	0.2		
Cast	85.5	10.5	1.		Zn, 3.0
Cast Tutania	91.4		0.7	7.62	Zn, 0.25
Cast Tutania	92.35	4.65	2.45	0.32	
Birmingham I	90.57	9.38	0.03		
Birmingham II	85.5	10.5	1.		Zn, 3.0
Sheet	91.5	7.1	1.4		
Sheet	90.6	7.8	1.5		
Spinning	93.7	3.75	2.6		
Spoons	88.4	8.7	2.9		
Spoons	85.5	14.4	0.15		
Spoons	84.7	5.0	3.7		Bi, 4.9; Zn, 1.
Spoons	88.42	8.68	2.8		
Spoons	85.42	14.42	0.15		
Spoons	84.46	5.62	3.68		Zn, 1.53; Bi, 4.88
Plate, Hard Spelter	90.62	7.81	1.46		
Plate, Birmingham	91.46	7.12	1.4		
Plate, Tutania	90.		2.7	6.0	Zn, 1.3
Plate, Deutsch (Ludenscheidt)	71.85	24.26	3.85		
German	84.	9.	2.		Zn, 5.
German	81.9	16.3	1.8		
German	70.82	15.10	4.91	9.21	
German, Various, Turn	93.65	3.75	2.63		
German, Queen's Metal	88.52	7.10	3.48		
Blatt-Silver	91.1			0.35	Zn, 8.25; Fe, 0.23
Bushing, Russian	72.2		1.3		Zn, 26.5
Clichier Metal	48.	10.5		32.5	Bi, 9.
Clichier Metal	80.			5.	Bi, 15.
Deurance Metal (Locomotive)	33.3	44.5	22.2		
Dudley Antifriction	98.13		1.6	0.25	
Fahrig Antifriction	90.		10.		
Gilding Foil	97.6		2.16		Fe, 0.11
Hard Head	90.	8.	2.		
Hammonia Metal	64.5		3.25		Zn, 32.25

A LIST OF ALLOYS (Continued)

TIN BASE ALLOYS (Continued)

	Sn	Sb	Cu	Pb	Other Elements
Hoyles Metal	46.	12.		42.	
Husmann Metal	73.6	11.	4.	10.6	Zn, 0.18; Fe, 0.22
Jacoby Metal	85.	10.	5.		
Kamarsch Bearing	85.	5.	3.6		Bi, 1.6; Zn, 1.4
Minofor (Brittania)	68.5	18.2	3.3		Zn, 10.
Minofor	66.	20.	4.		Zn, 9.
Navy Bearing	89.	7.3	3.7		
Navy Bearing, Hard	80.	15.	5.		
Parsons White Brass	60.		5.		Zn, 35.
Parsons White Brass	81.	11.	4.5	3.5	
Parsons White Brass	76.	6.	5.	13.	
Pewter	80.			20.	
Pewter	73.5	5.5	1.	20.	
Pewter	88.12	7.16	3.51		Zn, 0.88
Pewter	89.3	7.6	1.8	1.8	
Pewter	87.2	5.7	1.6	11.5	
Pewter	89.3	7.6	1.8	1.8	
Pewter	84.7	1.7	6.8		Bi, 6.
Phosphor Tin	95.				P 5.0
Phosphor Tin	90.				P, 10
Plastic Metal	80.5	8.6	9.5		Fe, 1.4
Poterie d'Etain	90.	9.	1.		
Prince's Metal	84.75	15.25			
Queen's Metal	50.5	16.5		16.5	Zn, 12.5
Queen's Metal	87.	8.5	3.5		Zn, 1.
Queen's Metal	73.36	8.88		8.8	Zn, 8.88
Queen's Metal	88.5	7.1	3.5		Zn, 0.9
Queen's Metal	88.5	7.	3.5		Bi, 1.0
Ships Nail Alloy	50.	17.		33.	
Silver Foil	90.				Zn, 10.
Silver Foil	97.5		2.5		
Stanniol	96.2		1.	2.4	Ni, 0.3; Fe, 0.1
Tinfoil	87.5	0.5	4.	8.	
Tourun Leonard's Metal	90.		10.		
Trabuk Metal	87.5	5.			Ni, 5.5; Bi, 2.
Tinsel	60.4			39.6	
Tutania, Cast	91.4		0.7	7.62	Zn, 0.25
Tutania, Cast	92.4	4.6	2.5	0.32	Fe, 0.13
Tutania, English	80.	16.	2.7		Zn, 1.3
Tutania, Plate	90.		2.7	6.0	Zn, 1.3
White Metal, Hanover	86.8	7.6	5.6		
White Metal Dutch	81.5	8.8	6.6		

LEAD BASE ALLOYS

	Pb	Sn	Sb	Cu	Other Elements
Accumulator Metal (Condenser Foil)	90.	9.25	0.75		
Aluminum Solder, Frismuth	27.	67.			Al, 3.
Antifriction	60.		20.		Zn, 20.
Antifriction	88.		12.		
Antifriction	84.		16.		
Antifriction	78.8		19.6		Zn, 1.
Antifriction	77.	10.	12.5	0.5	
Antifriction	77.	8.	14.	1.	
Battery Plates	94.		6.		
Bearing	80.5	11.6	7.4	0.5	
Bearing (Katzenstein)	77.6	7.3	16.8	0.4	
Bearing	73.0	8.5	18.0	0.4	
Bearing	68.0	9.6	20.5	1.6	
Bearing	71.	7.7	18.5	2.	
Bearing	62.5	26.2	10.	1.3	
Bearing	61.0	25.0	13.0	1.0	
Bearing	48.	40.	10	2.	
Bearing (American)	46.	36.5	16.5	1.0	
Bearing	40.	42.	16.	2.	

A LIST OF ALLOYS (Continued)

LEAD BASE ALLOYS (Continued)

	Pb	Sn	Sb	Cu	Other Elements
Bearing	37.	50.	12.	1.	
Bearing	25.5	61.	10.5	2.8	
Bearing	11.8	74.	9.5	4.7	
Bearing	10.	75.	12.	3.	
Bearing	86.	1.	13.		
Bearing	83.3	8.3	8.3	8.	
Bearing	82.	2.	16.		
Bearing	80.	10.	10.		
Bearing Compagnie de l'Est	80.	12.	8.		
Bearing	80.	5.	15.		
Bearing	76.	7.	17.		
Bearing, American Railroad	73.5	8.	18.5		
Bearing, French Railroad	70.	20.	10.		
Bearing, Paris-Lyon-Mediterranean Railroad	70.	10.	20.		
Bearing, American Railroad	68.	21.	11.		
Bearing, Graphite Metal	68.	15.	17.		
Bearing	62.	27.	10.		
Bearing	60.	20.	20.		
Bearing, Chemin de fer de l'est Franc	42.	42.	16.		
Bearing	40.	45.	15.		
Bearing, Italian Railroad	37.	38.	25.		
Bearing	10.	75.	15.		
Capsule Metal	92.	8.			
Clichier Metal	46.	33.			Cd, 21.
Clichier Metal	50.	36.			Cd, 14.
Clichier Metal	32.5	48.	10.5		Bi, 9.
Clichier Metal	5.	80.			Bi, 15.
Electrotype Metal	93.	3.	4.		
English Linotype	83.	5.	12.		
English Stereotype	82.5	4.5	13.		
Frary Metal	98.				Ba Ca 2.
Fahlun Brilliants	40.	60.			
Foil-Lead (Calin)	86.5	12.5		1.0	
French Auto	75.	10.	15.		
For Small Castings	5.	75.	20.		
Glievor Bearing	76.5	8.	14.		Fe, 1.5
"Glyco"	80.5	4.5	14.5		As, 0.5
Hard Lead	80.	46.	12.	0.5	
Hoyle's Metal	42.	46.	12.		
Hoyt Metal	96–90	1.	3.9		
Jacana Metal	70.	10.	20.		
Locomotive Bushing	65.6	8.8	15.4		
Linotype Metal	85.	3.	12.		
Mackenzie Metal	70	13.	17.		
"Magnolia"	78.	6.	16.		
"Magnolia"	79.75	5.	15.		Bi, 0.25
Marine Babbitt	72.	21.	7.		
Metallic Packing	82.25	4.75			
Metallic Packing, Compagnie d'Orleans	76.	14.	10.		
Mystic Metal	88.7		10.8		Bi, 0.1
Non-pareil	78.35	4.95	16.7		
Noheet	98.41	0.08	0.11		Na, 1.4
Pewter	11.5	87.2	5.7	1.6	
Pewter	20.	80.			
Piston Packing, Compagnie de Nord	73.	12.	15.		
Shot Lead	99.8				As, 0.2
Solder	60.	39.	1.		
Plumbers	66.6	33.3			
Half and Half	50.	50.			
Tinman's	33.3	66.6			
Stereotype Metal	82.	6.	12.		
Stereotype Metal	82.	3.2	14.8		
Stereotype Metal	76.	4.	20.		
Stereotype Metal	70.	7.	23.		
Stereotype Metal	67.	17.	18.		
Stereotype Metal	35.	60.	5.		
Tandem	77.7	5.9	16.8		
Tea Lead	98.	2.			
Terne Metal	88.25	18.	1.75		
Type Metal	70.	10.	18.	2.0	
English, Old	69.2	9.1	19.5	1.7	

A LIST OF ALLOYS (Continued)

LEAD BASE ALLOYS (Continued

	Pb	Sn	Sb	Cu	Other Elements
Type Metal (*Continued*).					
English	63.2	12.	24.	0.8	
English	60.5	14.5	24.2	0.8	
Krupp	59.6	12.	18.	4.7	Ni, 4.7; Bi, 1.
English	58.	15.	26.	1.	
English	77.5	6.5	16.		
German	75.	2.	23.		
German	60.	35.	5.		
German	60.	34.6	5.4		
German	60.	15.	25.		
Common	60.	10.	30.		
Common	55.5	40.	4.5		
Best	50.	25.	25.		
French	55.	22.	23.		
French	55.	15.	30.		
Alco	98.5				Ba Ca, 1.5
White	77.	5.	15.	2.3	
White	33.	53.	10.6	2.4	Zn, 1
White	33.9	49.1	13.6	3.3	

ZINC BASE ALLOYS

	Zn	Cu	Sn	Sb	Pb	Other Elements
Aluminum Solder, Frismuth	47.5	5.5	31.5			Al, 10.5; Ag, 5.5
Aluminum Solder, Frismuth	47.4	5.3	36.8			Al, 10.5
Aluminum Solder	30.		65.			Bi, 5.
Aluminum Solder	80.	8.				Al, 12.
Aluminum Solder	57.					Cd, 43.
Aluminum Solder, Mourey	94.	2.				Al, 4.
Aluminum Solder, Mourey	80.	8.				Al, 12.
Aluminum Solder, Bourbouse	81.82					Al, 18.18
Aluminum Solder, Cornande and Cruiys	52.		30.			Al, 17.5; Ni, 0.5
Aluminum Solder, Richards	25.		71.5			Al, 3.5
Battery Plates	63.4	3.2	21.3		12.	
Babbitt Metal	69.	5.	26.	3.	5.	
Bearing, Hard	90.	7.	1.5	1.5		
Bearing	88.	8.	2.	2.		
Bearing	85.	5.	10.			
Bearing	77.	5.5	17.5			
Bearing, English	67.7	7.1	14.9			
Bearing	66.5	4.2	29.3			
Bearing	55.	0.55	22.7			Al, 20.; Pb, 1.25
Biddery	90.2	6.3	0.8		2.6	
Biddery Henic's	84.3	11.4	1.4		2.9	
Birmingham, Platina	79.4	20.25				Fe, 0.33
Brittania, Cast	48.	3.	48.	1.	1.	
Button	80.	20.				
Cook's Alloy	31.5			68.5		(Zn, 43.; Sb, 57)
Dunnlevic and Jones	52.	1.6	46.	0.4		
Dunnlevic and Jones Antifriction	20.			20.	60.	
Dunnlevic and Jones Antifriction	85.	5.		10.		
Dunnlevic and Jones, Russian	80.	8.		10.		
Ehrhardt's Metal	89.	4.	4.		3.	
Ehrhardt's Type	89.	3.	6.		2.	
English White Metal	76.2	5.6	17.5			
Fenton's Alloy	80.	6.	14.			
Fenton's Alloy	80.	8.5		14.5		
Glievor Bearing	73.5	4.4	6.7	9.	5.	Cd, 1.4
Hamilton Metal	93.4	3.5		1.5	3.1	Phos, Sn. 5.
Heavy Axle	47.	1.	38.	6.	4.	
Hammonia Metal	32.25	3.25	64.5			
Iridium	77.25	1.12	21.63	Trace		
Iridium	83.00	1.25	15.75	Trace		
Kemlet	67	9				Al, 15.
Kneiss Metal	50.		25.		25.	

A LIST OF ALLOYS (Continued)

ZINC BASE ALLOYS (Continued)

	Zn	Cu	Sn	Sb	Pb	Other Elements
Kneiss Metal	40.	3.	15.		42.	
Leddel Alloy	90.	5.				Al, 5.
Ledebur's Bearing	85.	5.		10.		
Ledebur's Bearing	77.	5.5	17.5			
Leddel Bearing	87.5	6.25				Al, 6.25
Lumen	86.	10.				Al, 4.
Lumen	85.	10.				Al, 5.
"Hartzink"	91.9	0.13			2.4	Fe, 5.3
Parsons White Brass	30.	5.	65.			
Pierrot Metal, Beugnot	83.3	8.3	7.6	3.5	3.	
Propeller Bushing	69.	5.	19.	7.		
Pump Cocks	72.	7.	21.			
Russian, Packing	98.5		0.98		0.32	Fe, 0.16
Russian	26.5	1.3	72.2			
Salge Metal	85.5	4.	9.9		1.1	
Schomberg-Bearing	59.4	0.38	39.8		0.21	Fe, 0.15
Silver Leaf	8.25		91.		0.35	
Silver Metal	66.5					Ag, 33.5
Siemens Halske	48.			5.		Cd, 47.
Siemens Halske, Automobile	47.5			5.		Cd, 47.5
Sorel's Alloy	98.	1.				Fe, 1.
Sorel's Alloy	88.	10.				Fe, 10.
Spiauter (Hard Zinc)	90.	2.		8.		
Vaucher's Alloy	75.		18.	2.5	4.5	
Zelco	73	2				Al, 15.0

FUSIBLE METALS

	Bi	Sn	Pb	Cd	Other Elements	Temperature of Fusion
Anatomical Alloy	53.5	19.	17.		Hg, 10.5	60° C.
Bismuth Solder	40.	20.	40.			
Bismuth Solder	33.3	33.3	33.3			
Bismuth Solder	27.5	45.	27.5			
Bismuth Solder	25.	50.	25.			
D'Arcet	50.	25.	25.			
Eutectic	52.5	15.5	32.			96° C.
Eutectic	49.5	13.1	27.3	10.1		70-74° C.
Eutectic	51.6		40.2	8.1		91.5° C.
Eutectic	54.	26.		20.		103° C.
Eutectic		50.	32.	18.		145° C.
Fusible Tea Spoons	44.5	16.5	30.		Hg, 5-10	
Guthrie's	47.38	19.97	19.36	13.29		
Lictenberg	50.	20.	30.			
Lipowitz	50.	13.3	26.7	10.		
Newton's	50.	18.75	31.25			
Onion's	50.	20.	30.			
Rose's	50.	22.	28.			
Rose's	35.	30.	35.			
Wood's	50.	12.5	25.	12.5		

GOLD ALLOYS

	Au	Ag	Cu	Other Elements
Standard Gold, British	91.66		8.33	
Standard Gold, U. S	90.		10.	
22 Carat	91.66	4.166	4.166	
22 Carat Dental, Dark	91.57	4.99	3.44	
22 Carat Dental, Light	91.57	8.43		
20 Carat	83.33	8.33	8.33	

A LIST OF ALLOYS (Continued)

GOLD ALLOYS (Continued)

	Au	Ag	Cu	Other Elements
20 Carat	83.20	10.81	5.99	
18 Carat	75.0	10.4	14.6	
18 Carat	75.00	12.00	13.00	
18 Carat	75.00	14.6	10.4	
18 Carat Dental	74.88	19.13	5.99	
18 Carat Special	75.00	20.00	5.00	
16 Carat	66.6	6.6	26.6	
16 Carat	66.66	11.12	22.22	
16 Carat	66.6	19.4	13.8	
16 Carat	66.45	25.57	7.98	
15 Carat	62.49	11.01	13.25	
14 Carat	58.3	4.16	37.5	
14 Carat Regular	58.33	13.33	28.34	
14 Carat Spring	58.33	16.00	25.67	
14 Carat	58.3	25.	16.6	
14 Carat Special	58.33	27.77	13.90	
14 Carat Dental	58.03	30.03	11.94	
12 Carat	50.00	14.58	35.42	
10 Carat Regular	41.66	12.34	46.00	
10 Carat	41.6	16.6	41.6	
10 Carat Spring	41.66	20.00	38.34	
8 Carat	33.30	20.00	46.70	
Yellow Gold	53.	25.	22.	
Red Gold	75		25.	
Dark Red Gold	50.		50.	
Pale Yellow Gold	91.6	8.3		
Pale Yellow Gold	91.6			Fe, 8.3
Green Gold	75.	25.		
Green Gold	75.	16.6		Cd, 8.3
Green Gold	74.6	11.4	9.7	Cd, 4.3
Green Gold	75.	12.5		Cd, 12.5
Grey Gold	85.7	8.6		Fe, 5.7
Grey Gold	83.3			Fe, 16.6
Blue Gold	75.			Fe, 25.
White Gold	90.			Pd, 10
Palladium Gold	90.			Pd, 10
White Gold	75-85			Ni, 10-8; Zn, 2-9
Gold Solders:				
18 Carat	75.	13.	12.	
18 Carat	62.5	31.25	6.25	
16 Carat	75.	16.6	8.3	
14 Carat	50.	33.3	16.6	
12 Carat	47.8	29.	17.1	Brass, 6.1
10 Carat	41.2	37.	21.2	Brass, 0.6
9 Carat	25.	50.	25.	
8 Carat	40.	36.6	23.4	
Best	62.5	22.5	15.	
Easy Melt	54.5	31.75	13.75	
Very Easy Melt	11.5	54.5	28.5	Zn, 5.5

SILVER ALLOYS

	Ag	Cu	Zn	Sn	Other Elements
Sterling Silver	92.5	7.5			
Rupee	91.6	8.3			
Standard	90.	10.			
Silver Solders:					
Hard	80.	13.2	6.8		
Sterling	80.	2.5	17.5		
Medium	75.	20.	5.		
Medium	70.	22.5	7.5		
Enamel	66.7	33.3			
Pure Silver	72.	28.			
French	66.	23.3	10.		

A LIST OF ALLOYS (Continued)

SILVER ALLOYS (Continued)

	Ag	Cu	Zn	Sn	Other Elements
Silver Solders (*Continued*)					
Plate	64.5	22.5	13.		
Common	62.5	30.	7.5		
Chain	62.5	31.2	6.2		
Chain	63.5	20.9	16.6		
Quick	62.5	20.9	10.4	6.2	
Quick	56.9	27.7	11.5	3.8	
Bureau of Standards	40.	14.	6.	40.	
Argent Francais (Roulz)	40.	35.			Ni, 25.
Argent Francais (Roulz)	33.	40.			Ni, 27.
Argent Francais (Roulz)	20.	50.			Ni, 30.
Argent Francais (Odessa)	33.25	42.5	15.75		Ni, 8.5
Argent Francais, Mousset's Silver	27.5	59.5	9.5		Ni, 3.5
Proplatinum	23.57				Ni, 72.; Bi, 3.72; Au, 0.71

PLATINUM, ETC.

	Pt	Au	Ag	Other Elements
Thermo-couples	90.			Ir, 10.
Thermo-couples	90.			Rh, 10.
Solder	27.		73.	
Resistance	33.3		66.6	
Platine-au-titre	17-35		83-65	
Platinum-Gold:				
White	40.	60.		
Almost White	30.	70.		
Almost White	58.3	16.6	25.	
Cooper's Gold	18.75			Cu, 81.25
Cooper's Gold	29.17			Cu, 66.6; Zn, 4.15
Cooper's Pen Metal	50.		37.5	Cu, 12.5
Cooper's Pen Metal		25.	25.	Cu, 50.
Cooper's Mirror	9.5			Cu, 58.; Sn, 27.5; Zn, 3.5; As, 1.5
Palladium Gold		31.	19.	Pd, 10.35; Cu, 39.65
Platinum Substitutes:				
Palau		80.		Pd, 20.
	20.			Ni, 60.; Pd, 10.; V, 10.
Cooper's	25.		70.	Ni, 5.
Cooper's			70.	Co, 5.; Pd, 25.
Electrical	7.5	67.5	25.	
Electrical	5.	70.	25.	
Electrical		70.	25.	Ni, 5.
Proplatinum		0.75	23.5	Ni, 72.; Bi, 3.75

RESISTANCE ALLOYS

	Ni	Cr	Fe	Mn	Cu	Zn	Other Elements
Advance	44.3		0.5	1.15	53.9		
Argentan	26.		1.		56.	18.	
Calido	64.	8.	25.	3.			
Calorite	65.	12.	15.	8.			
Calorite	65.	12.	23.				
Chromel A	80.	20.					
Chromel B	85.	15.					
Chromel C	64.	15.	25.				
Climax	24.4		73.	2.6			
Comet	30.4	2.2	66.9	0.8	0.4		
Constantin	46.				54.		
Constantin	43.9		0.4	1.34	54.15		
Dilver	(See Platinite)						

A LIST OF ALLOYS (Continued)

RESISTANCE ALLOYS (Continued)

	Ni	Cr	Fe	Mn	Cu	Zn	Other Elements
Eureka	(See Manganin)						
Excello	85.	14.	0.5	0.5			
Fermet	18.	4.	Bal.	2.2	0.3		W, 0.5-1.0; C 0.35
Ferrozoid	Nickel steel						
Ia-Ia	40.				60.		
Ideal	45.		0.66	0.45	53.4		Al, 0.66
Ideal	40.		1.	1.	58.		
Invar	36.		64.				
Kromax	80.	20.					
Kromore	85.	15.					
Kruppin	28 per cent Nickel Steel						
Lucerno	67.9		2.4	2.2	27.5		
Magno	95.			5.			
Manganese Steel			Bal.	12.			C, 1.2
Manganin	4.			12.	84.		
Manganin	2.			12.	86.		
Manganin	12.			4.	84.		
Manganin	2.3		0.6	15.	82.1		
Manganin	5.			25.	70.		
Marsh's Patent	75.	25.					
Monel	67.1		2.1	1.7	28.4		
Nichroloy	75.	16.	8.	3.			
Nichroloy	40.	7.	50.	3.			
Nichroloy	23.	20.	50.	1.			
Nichrome I	60.	11.	25.	4.			
Nichrome II	75.	11.	12.	2.			
Nichrome	66.	22.	10.	2.			
Nickelin	18.				62.	20.	
Nickelin	32.				68.		
Nickelin	31.5				55.3	13.1	
Ni-Cr-Cu	80.	25.			20.		
Ni-Cr-Cu	85.	20.			15.		
Ni-Cr-Al	88.	8.					Al, 12.
Non-Magnetic High Resistance	30.	70.					
Phenix	25.		75.				
Placet	60.	15.	20.	5.			
Platinite	46–42		54–58				
Platinoid	24.77		0.47	0.15	54.	20.4	
Platinoid	14.				60.	24.	W, 1–2
Rayo	85.	15.					
Resistin			1.8	11.7	86.5		
Resistin			3.	12.	85.		
Rheotan			12.	2.	84.	4.	
Rheotan II	25.		5.		52.5	18.	
Silver Bronze				18.	67.5	13.	Al, 1.25; Si, 0.25
Tarnac	(See Manganin)						
Tico	30.4		67.3	1.12	1.1		
Tophet	61.	10.	26.	3.			
Vestalin	(28 per cent Nickel Steel)						

HEAT RESISTING ALLOYS

	Ni	Cr	Fe	Cu	Mn	Other Elements
Aluminum Bronze.						
Armstrong		12.	Bal.			Si, 5.; C, 0.45
Calite	35.0	5.0	50.0			Al, 10.0.
Clebrium	2.0	13.1	Bal.		0.75	Mo, 3.6; Si, 1.5; C, 2.6
Clebrium	4.6	18.5	Bal.	2.	2.8	C, 2.0
Cobaltcrome		13.6	79.5		0.2	Co, 3.7; Mo, 0.8; Si, 0.8; C, 1.5
Duke's Metal		11.76	80.8		0.2	Si, 0.6; C, 1.45; Co, 4.; W, 0.35
Flame Resisting	9.7	14.	Bal.		0.77	Si, 0.2; C, 0.23
Ludlum		13-17	Bal.			Si, 1.; C, 0.4; Mo, 1.
Monel Metal.						

A LIST OF ALLOYS (Continued)

HEAT RESISTING ALLOYS (Continued)

	Ni	Cr	Fe	Cu	Mn	Other Elements
Nichrome	70.3	20.	6.9		1.9	Si, 6.5
Nichrome	53.7	16.7	22.4		1.4	Si, 1.0
Nichrome	80.	13.55	4.8			Si, 1.3
Nichrome	60.2	11.1	27.2		1.2	C, 0.3
Nichrome	61.2	9.9	26.9		1.0	Si, 0.3
Nichrome	64.7	13.3	6.4	11.	0.63	Si, 3.36; C, 0.35
Nichrome	70.3	13.2	7.25	3.25	0.2	Si, 3.7; Mo, 1.33
Nichrome	67.8	11.3	6.95	7.1		Si, 4.65; Ti, 0.25
Nichrome	62.	13.	20.		5.0	
Nickel Steel	30.	1.0	Bal.		1.0	
Resistal	16.56	15.14	Bal.			Si, 4.66; C, 0.3
Silchrome		9.5	Bal.			Si, 4.; C, 0.5
Silchrome Wire		18.	Bal.			Si, 3.; C, 0.3; W, 3.

NON-CORROSIVE ALLOYS

	Cr	Co	Ni	Cu	Fe	Other Elements
Bario (sheet)	4.25		90.			W, 1.2; Si, 0.3
Bario-Metal, Soft	20.	60.				W, 20.
Bario-Metal, Hard	30.	30.				W, 25.; Mn, 10.; Ti, 5.
Borcher's	30.	35.	35.			
Borcher's	30.	34.	34.			Ag, 2.
Borcher's	30.	35.	35.			Mo, 0.5-5
Borcher's	36.				60.	Mo, 4.
Borcher's	65.				35.	
Brix	15-20		60-75	5.		Si, 4.; W, 1-4; Al, 2.; Mn, Ti 3; B, 1
Cobaltcrome	13.6	3.7			79.5	Mo, 0.84; Si, 0.8; C, 1.5
Cobaltcrome	30-25	5-10			70-60	
Cufenium			22.	72.	6.	
Cuniloy			65.	25.		Mn, 35.; Pb 1.
Delhi	18.					Si, 1.5; C, 0.3-0.6; Mn, 0.3
Duke's Metal			40.	30.	30.	
Duke's Metal	11.8	4.7			89.8	W, 0.35; Si, 0.6; C, 1.45
Haynes Metal	20-30	5-25			10-75	
Haynes Metal, Hard	15.	45.				W, 40.
Haynes Metal, Soft	10.	62.				W, 28.
Ilium	21.		62.5	6.5	1.	Mo, 5; W, 2; Mn, 1; Al, 1.
Krupp's V1M	14.25		2.25		Bal.	C, 0.1
Krupp's V2A	23.		9.5		Bal.	C, 0.4
McFarland and Harder	43.		46.	11.		
McFarland and Harder	30.		59.	11.		
McFarland and Harder	10.		48.	43.		
McFarland and Harder	16.		29.	55.		
Nevastain	9.5				Bal.	Si, 3.8; C, 0.43
Non-Oxidizable, Lemarquand		8.	7.0	39.		Zn, 37.; Sn, 9.
Non-Oxidizable, Martics'			35.	17.	10.	Zn, 18.; Sn, 10.
Parr	15.		80.	5.		
Parr	18.		66.6	8.5		W, 3.3; Al, 2.0; Mn, 1.; Ti, 0.2; B, 0.2
Sea Water	1.2		24.		Bal.	Mn, 0.6; Si, 0.35; C, 0.5
Sea Water			16.7			Mn, 5.; Si, 0.3; C, 0.7
Sideraphite			23.	5.	63.	W, 4.; Al, 5.
Stainless (Armstrong)	12.				Bal.	Si, 5.; C, 0.45
Stainless (Brearley)	13.				Bal.	C, 0.3; Mn, 0.3
Stellite	25.	75.				
Stellite	25.	70.				W, 5
Stellite	15.	60.				W, 25
Stellite	15.	55.				W, 25; Mo, 5.
Stellite	15.	45.				Mo, 40.
Stellite	20-23	55.			3-5	W, 15-20; C, 1.5-4.0
Stellite	33.6	55.6				W, 9.2; C, 1.5
Stellite	26.4	34.5			10.	W, 12.5; Mo, 9.5; C, 1.8
Stellite	13.2	60.8			0.5	Mo, 24.1

A LIST OF ALLOYS (Continued)

NON-CORROSIVE ALLOYS (Continued)

	Si	Mn	C	P	S
Duriron	14-14.5	0.25-35	0.2-6	0.16-0.2	0.005C
Duriron	14-15	2-2.5	0.75-1.25	0.05-1	0.05-0.15
Corrosiron Ironac Elianite Buflocost Tantiron	Similar				

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